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AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 58

WASHINGTON
GOVERNMENT PRINTING OFFICE
1902

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

STORAGE OF WATER

ON

KINGS RIVER, CALIFORNIA

BY

JOSEPH BARLOW LIPPINCOTT

WASHINGTON

GOVERNMENT PRINTING OFFICE

1902

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., June 29, 1901.

SIR: I have the honor to transmit herewith a manuscript prepared by Mr. J. B. Lippincott, giving the results of surveys and investigations for water storage and power development on Kings River, California. This investigation was begun as part of the general plan for ascertaining the water resources of the country and the extent to which the Arid Lands could be redeemed by irrigation.

In order to assist this work and make it more complete the California Water and Forest Association, organized to promote the irrigation developments of the State, placed at the disposal of the Geological Survey the sum of $1,000, which had been raised by private subscription. In addition to this a local organization known as the Kings River Storage Association, cooperating with the other body, increased the amount by $1,500, to be used for field expenses.

In this work the drainage basin of Kings River has been explored and preliminary surveys and estimates prepared sufficient to justify the statements that works can or can not be economically constructed at certain localities. It is not the object of this investigation to make finished working plans or final surveys upon which specifications or contracts could be made, that detail being left to those who may have in charge the actual construction of the works. It is believed, however, that the estimates are sufficiently broad and conservative to enable general conclusions to be drawn. It is understood that the officers of this Survey have no concern with the question whether such works are to be built by private capital or by public funds, their object being to ascertain the important physical features.

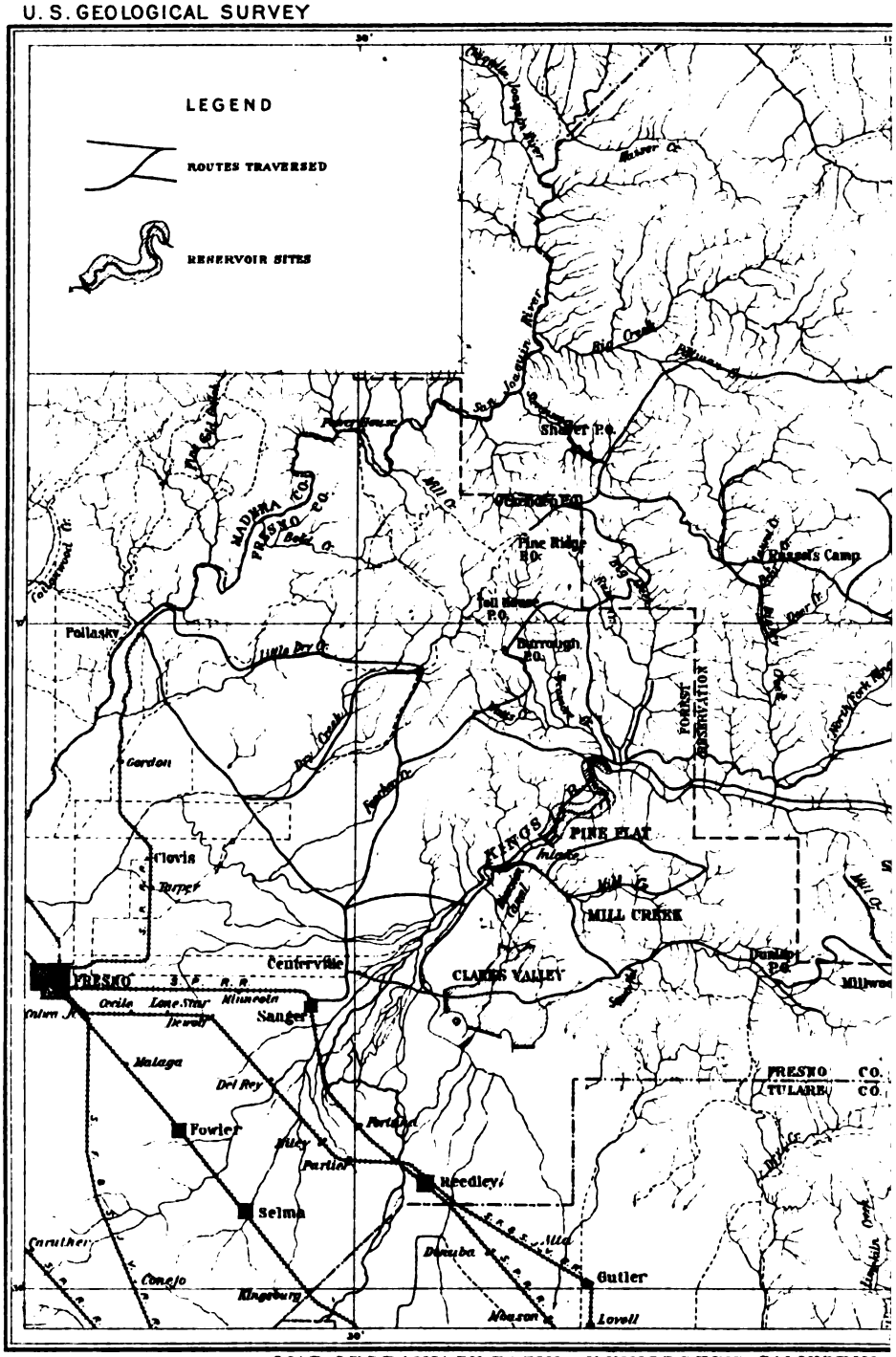
The situation on Kings River is to a certain extent typical of that along a number of important streams of the West, and as a result of this investigation it is believed that the reclaimable area can be greatly extended by the construction of storage works and also of power plants by means of which, through electrical transmission, pumps can be operated at small expense out on the broad valleys. The demonstration of these conditions will prove one of the most important steps toward the transformation and utilization of the fertile but arid lands.

Very respectfully,

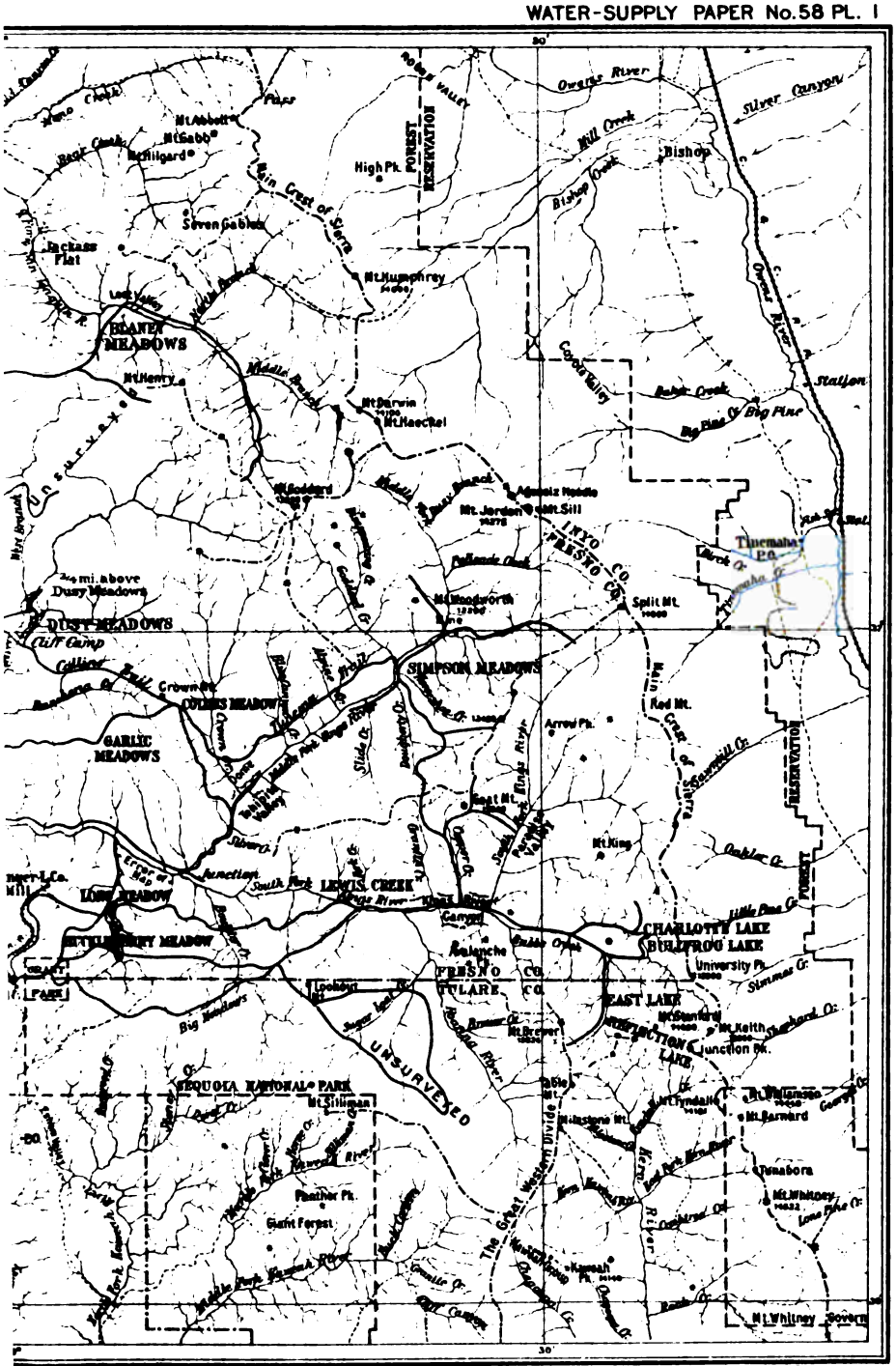
F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

U. S. GEOLOGICAL SURVEY



MAP OF DRAINAGE BASIN OF KINGS RIVER, CALIFORNIA



SHOWING ROUTE TRAVERSED BY EXPLORING PARTIES

JULIUS BIEN & CO. LITH. N.Y.

STORAGE OF WATER ON KINGS RIVER, CALIFORNIA.

By JOSEPH BARLOW LIPPINCOTT.

LOCATION AND PHYSICAL FEATURES.

Kings River rises on the western slope of the Sierra Nevada, in Fresno County, Cal., draining the crest from Mount Whitney on the south to Mount Goddard on the north. Mount Whitney, with an elevation of 14,898 feet, is the highest mountain in the United States. The divide to the north culminates in numerous peaks, which reach elevations greater than 14,000 feet. This crest probably displays the most rugged and the grandest scenery in our country. Above the 10,000-foot contour the drainage basin of the river is largely bare granite, supporting a scanty vegetation and carved by the action of glaciers. This is clearly shown in Pl II, *A*, and in Pl. III. Between the 10,000- and the 1,000-foot contours the mountains are covered with underbrush and large timber, the most extensive forest of *Sequoia washingtoniana* growing here. (See Pl. IV, *A*, a view southeast of Millwood, at an elevation of 6,000 feet.) The distance from the crest of the mountains to the mouth of the canyon of the river, on a direct line, is approximately 50 miles. Fully 80 per cent of the drainage basin is now included within the boundaries of the Sierra Forest Reserve, which is patrolled for the prevention of fires and illegal herding. The Government will grant no more private holdings within the reserve except for mining or the development of the water resources. This is of prime importance to the irrigated lands below, for it means the conservation of the stream, and the action has been taken none too soon, for great destruction of the forests has already been occasioned by fires and lumbermen. The largest grove of big trees in the State is now being sawed up at Millwood. Pl. IV, *B*, is a view in the Converse Basin, and shows the wasteful, destructive lumbering that has been carried on there.

The river debouches from its mountain drainage basin upon the plains of Fresno, Kings, and Tulare counties. These lands are sometimes referred to as the Kings River delta. They are near the geographic center of the State. Fresno and Hanford are the principal towns. They are about 200 miles distant from San Francisco and Los

Angeles. The counties referred to present a variety of climatic conditions and soils. The altitudes vary from 250 to 14,000 feet. The Coast Range on the west consists of rolling hills, and the country between those mountains and the Sierra Nevada, to the east, is a valley comprising river bottoms and uplands. The Sierra Nevada is divided into three regions—the foothill region, the timber or forest region, and the region of snow and ice. It will readily be understood that with so varied a topography a variety of climatic conditions would necessarily exist. The yearly seasons in San Joaquin Valley are two—a dry season and a wet season. The former usually begins about May 1 and lasts until about the middle of October or the first of November, when the rainy season begins. The average rainfall is 8.79 inches annually at Fresno. There are about 275 days of sunshine in the year. The rains in the winter seldom last more than two or three days at a time. With the exception of very rainy days there is no time during the year that men and teams can not work out of doors. The mean average winter temperature is about 60°; the average summer temperature is 80°. The atmosphere during the summer months is dry, and the heat is not nearly so oppressive as in localities where the atmosphere is damp. The health reports show that Fresno has the lowest death rate of any city in the State. The mountain regions of the eastern portion of the district are always cool. They can be reached in about eight or ten hours' drive from Fresno.

There are probably few equal areas of country where a greater variety of valuable commodities are produced than here. Lumber, gold, copper, petroleum, grain, oranges, lemons, many varieties of deciduous fruits, grapes, raisins, wines, and brandies are produced in commercial quantities. There are more than 500,000 deciduous fruit trees in Fresno County, and the number is being increased each season. There are about 40,000 acres of vineyards producing raisin and wine grapes.[a]

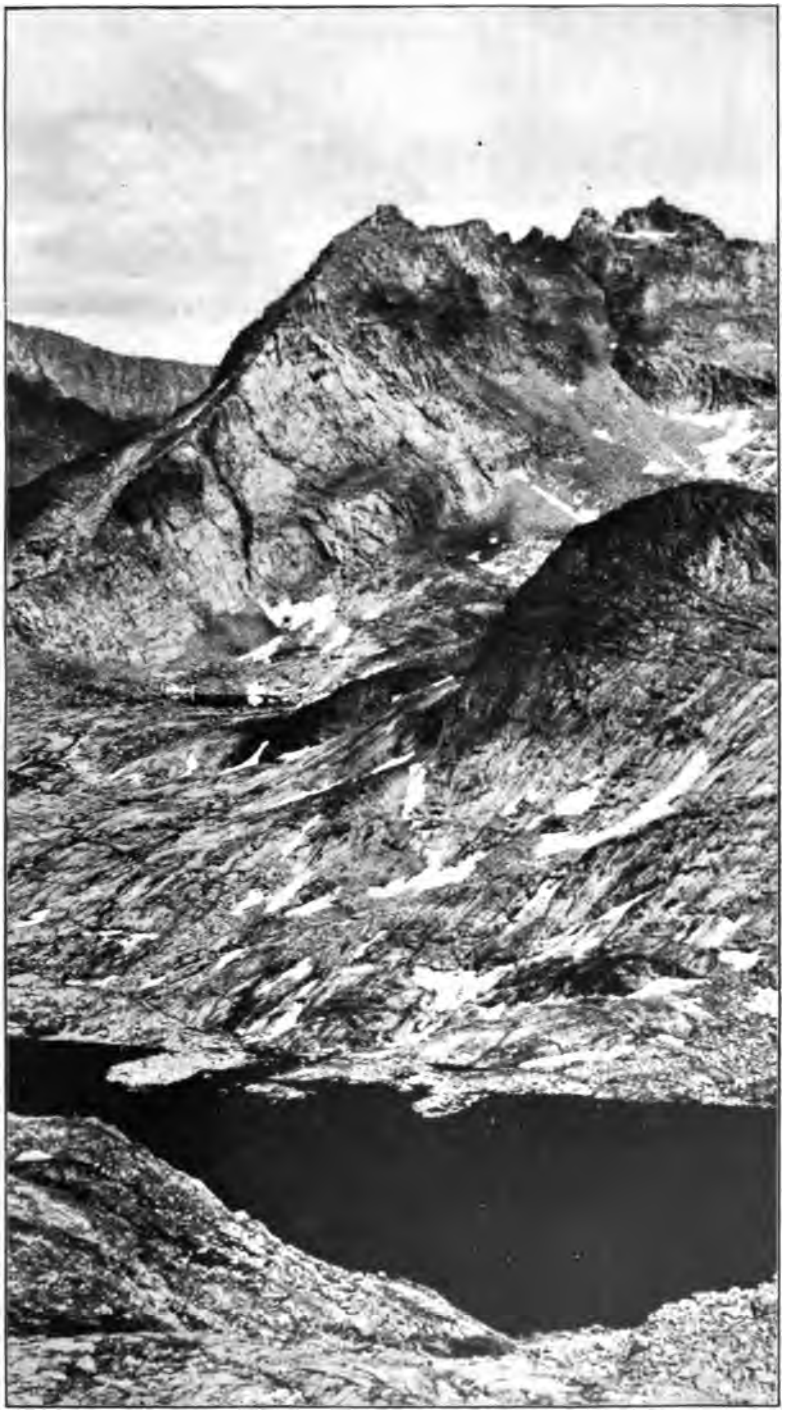
Irrigation is necessary for the production of all varieties of agricultural products, with the possible exception of grains. There are about 625 miles of main irrigation canals, covering 380,000 acres of land on the Kings River delta. It is believed that a good water right on valley lands will add $50 per acre to their value and $90 per acre to the value of the so-called frostless foothill lands. The duty of water may be taken at 2 acre-feet, or 24 inches in depth, each year. Thus an acre-foot of water is worth from $25 to $45 delivered to the land.

As Kings River leaves its canyon, about 12 miles east of Sanger, in Fresno County, it is immediately diverted by a series of canals, shown on the map of the valley lands (Pl. V). The areas irrigated from the river, extending from Fresno on the north to Hanford on the south,

[a] In the fall of 1901 1,400 carloads of oranges were shipped from the district between Fresno and Porterville, and this industry is only in its infancy.

A GENERAL VIEW OF UPPER DRAINAGE BASIN OF KINGS RIVER.

B. HEADWORKS OF FRESNO CANAL AND IRRIGATION COMPANY'S SYSTEM.



CREST OF SIERRA NEVADA ABOVE TIMBER LINE, KINGS RIVER BASIN.

are the most extensive that are watered from any one stream in the State. The canal companies which associated themselves in the Kings River Storage Association decided to contribute for the investigation amounts proportional to the areas of land served. For this purpose each company filed with the association statements of the areas irrigated. These figures, which are given below, possibly represent the areas that are irrigated in good years during the period of spring flood of the river, and in some cases may be in excess of the land actually watered. These canals all have headworks of a rather temporary nature, consisting of rock-filled cribs or brush and rock dams, as shown in Pl. II, *B*.

Lands served by canal companies diverting water from Kings River.

	Acres.
Fresno canal, whole system	160,000
Laguna canal	25,000
Alta Irrigation Company's canal	50,000
Peoples' canal	25,000
Last Chance canal	25,000
Centerville and Kingsburg canal	20,000
Murphy Slough Association	20,000
Lower Kings River	15,000
Fowler Switch canal	12,000
Stinson canal	12,000
Crescent canal	12,000
Emigrants' canal	3,000
Liberty canal	750
Total	379,750

During the May and June flood period there is usually water for the full capacity of all of the diverting canals, estimated at 4,000 second-feet, but the available supply diminishes rapidly after the middle of June, as prior rights take precedence in the diversion. The area watered is on the eastern side of the middle portion of San Joaquin Valley. The lands have a gentle westerly slope from the foothills to the thalweg of the valley. The area irrigable from the river is far in excess of the available water supply. The distance from the foothills to the central drainage lines of the valley is about 40 miles.

This is the great raisin district of California. As already stated, many varieties of deciduous fruits are also successfully grown, and along the foothills it has been demonstrated that semitropical fruits can be matured with success where water is available for continuous irrigation. Porterville, about 50 miles to the south, is one of the most successful orange and lemon districts in the State, and it has been shown, by many scattered orchards, that these fruits can profitably be grown to the east of Sanger. Along the foothills of San Joaquin Valley marked increase in winter temperature occurs within

a rise of a few hundred feet. The citrus belt, as is the case in southern California, is a narrow strip of land at the base of the mountains.

The first irrigators on Kings River naturally diverted the water to the lower flat lands, where canals could be more cheaply constructed. In that way the water rights of the river have been applied to those lands, which are relatively low in elevation and upon which the citrus fruits, the most valuable crop, can not be raised. An increase in the water supply will therefore permit the application of a portion of this water to the valuable foothill lands. The deciduous fruits, which are gathered largely during the month of July, do not require extensive late summer irrigation. The reverse is true of citrus fruits, which do not ripen until November or December and which require irrigation throughout the summer. In a similar way alfalfa, the staple forage crop of the State, must be irrigated throughout the summer season. In this portion of California lands which are sown to grain are capable of producing two crops in case a water supply is available for late summer irrigation. An increase in the water supply will therefore permit improved irrigation for areas now served, as well as an extension of the irrigated area.

The combined capacity of the canals leading out of Kings River is stated to be approximately 4,000 cubic feet per second. In September, 1898, the low-water summer supply of the river fell as low as 145 cubic feet per second. Possibly the canals during spring floods can divert more than 4,000 second-feet of water, but not more than 4,000 second-feet if applied beneficially. It is therefore evident that the late summer supply is wholly inadequate for the demands of the water companies. (This is clearly shown in the discharge diagrams, Pls. VII and VIII.) The division of this late water has resulted in much litigation, and it is estimated that the canal companies have expended annually about $40,000 in legal controversies over it. This represents 4 per cent interest on $1,000,000, and results in much bad feeling and in no increase in the supply. During the spring and early summer there is an excessive water supply for all companies, and much water is unused. Little if any water is diverted during the midwinter season. If summer water could be supplied with certainty it is believed that midwinter irrigation would be practically abandoned. The water-power development considered in this report is on the Middle Fork of Kings River, above all diversions for irrigation and above the contemplated diversion of storage water to Clarks Valley, so that neither one would interfere with the proposed power plant.

During the last season (1900) the profits from the irrigated districts around Fresno have exceeded, it is estimated, $2,000,000. This illustrates what could be accomplished by extending the irrigation systems throughout the central valley of California. Land favorably situated and with a good water right sells for about $60 an acre when unimproved, and when in vineyard or orchard it will earn very good returns

A. FOREST COVER IN SIERRA NEVADA AT ALTITUDE OF 6,000 FEET.

B. DESTRUCTIVE LUMBERING IN SIERRA NEVADA.

on that value. The same class of land without an irrigation supply sells for about $10 an acre. The water supply therefore represents a value of $50 an acre. The water has usually been sold with the land. Under the Fresno canal a continuous flow of 1 second-foot originally sold for $1,600 and was made to apply to 160 acres of land, or at the rate of $10 an acre. An additional charge of 62 cents per acre per year is also made for conveyance of water and repairs. Water rights for 160,000 acres of land have been sold by this canal. In the Alta irrigation district the first cost of water was $5 an acre, with an annual charge of 40 cents per acre for cost of operating. There are 130,000 acres under this system. The rights of the Alta district to the river water are subsequent to those of the Fresno canal. A detailed description of these canals and their rights is contained in Water-Supply and Irrigation Paper No. 18, entitled Irrigation near Fresno, by C. E. Grunsky. The lands of the Kings River delta are described by Mr. Grunsky as follows:

Near Centerville the soil of the upland is a red sandy loam, resting on a yellow clay hardpan, which is usually at 4 to 6 feet below the surface. Hardpan is not continuous; it disappears frequently at about one-half mile from the margin of the upland, where the surface soil becomes lighter and more sandy. At depths of 10 feet or more beds of cobble and gravel are found, which in proximity to the low river bottoms afford thorough underdrainage to these lands. The soil is very productive. Ground water is at 12 to 15 feet below the surface.

Westward from Centerville toward Fresno the soil of the plains is a loamy sand. This generally rests on a firm clay hardpan, which is sometimes impregnated with sand. Soil is from 1 to 3 feet deep. At the sinks of the several creeks near Fresno the soil is a deep, heavy, red loam, baking on the surface after being wet. Where a hardpan substratum is encountered at all it is at 10 to 30 feet below the surface. Westward from the immediate vicinity of the sinks of the creeks the soil is a loamy sand, several feet deep, resting on a firm clay hardpan. The soil far toward the southwest merges into the sandy soils of the alkali belt which skirts the edge of Fresno Swamp, and these in turn are succeeded by the rich peaty alluvium of the swamp lands. To the south of Fresno the sandy soil of Fresno and central California colonies changes to the light so-called ash of Washington colony. The hardpan dips farther below the surface toward the south, and there are points in the latter colony where it has disappeared altogether. In the southern and southeastern portion of the region commanded by this canal system sand predominates. The surface of the country is comparatively smooth, though occasionally crossed by low sand ridges. Firm hardpan partaking of the nature of cemented sand, immediately below the surface soil is rarely found. It occurs most frequently where the surface presents the peculiar hog-wallow appearance.

PRECIPITATION.

The precipitation on the plains between Fresno and Hanford varies from 6 inches in the central portion of the valley to 9 inches at Fresno and 16 inches at Centerville. The only crop raised without irrigation is grain, and this fails except when the rains are opportune. The precipitation in the drainage basin ranges from 9 inches in San Joaquin Valley, at Fresno, to fully 50 inches on the crest, where it is largely in the form of snow, which lies in great depths on the high

divide until melted by the summer's heat. The accompanying tables give the annual precipitation at Fresno from 1877 to 1900, both inclusive, and at Sacramento from 1849 to 1900, both inclusive.

Annual precipitation, in inches.

FRESNO, CAL.

[Latitude, 36° 43′; longitude, 119° 49′; elevation, 293 feet; observer, Pacific Railway System.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1877-78	0.00	0.00	0.88	0.42	3.20	1.76	1.91	0.78	T.	0.00	0.00	0.00	8.95
1878-79	0.00	.20	.56	.22	1.28	.56	.66	1.33	0.06	0.00	0.00	0.00	4.87
1879-80	0.00	.55	.48	1.67	.46	2.14	.61	1.97	.15	0.00	0.00	0.00	8.43
1880-81	0.00	0.00	.44	3.05	2.21	.87	.55	1.00	.10	0.00	T.	T.	8.22
1881-82	.46	.36	.27	.16	.42	1.04	1.26	1.23	.10	0.00	0.00	0.00	5.30
1882-83	.34	.05	.73	.70	0.00	.57	2.46	.95	1.36	0.00	0.00	0.00	7.16
1883-84	0.00	2.00	T.	.34	2.29	3.18	2.81	2.85	1.11	1.29	0.00	0.00	15.87
1884-85	0.00	.35	.08	3.98	.45	0.00	.53	1.11	.15	0.00	0.00	0.00	6.65
1885-86	0.00	.06	7.92	1.90	2.38	.58	1.21	2.57	0.00	0.00	0.00	0.00	16.62
1886-87	0.00	.47	.70	.34	.31	2.80	.09	2.65	.03	.02	0.00	0.00	7.41
1887-88	.49	.15	.32	1.16	1.75	.13	1.95	.22	.56	T.	T.	T.	6.73
1888-89	.06	0.00	2.38	1.71	.34	.32	2.07	.54	.57	0.00	0.00	T.	7.99
1889-90	0.00	3.17	1.39	3.87	2.12	.80	1.04	.17	.45	0.00	0.00	T.	13.01
1890-91	1.26	0.00	.22	2.30	.79	2.03	.81	.55	.03	.02	0.00	0.00	8.01
1891-92	.39	0.00	.21	3.08	.37	.68	1.31	.22	1.30	0.00	0.00	0.00	7.56
1892-93	0.00	.31	.52	2.02	.74	1.75	3.09	.27	0.00	0.00	0.00	0.00	8.70
1893-94	0.00	T.	.13	.99	1.73	2.95	.25	.10	1.30	1.08	0.00	0.00	8.53
1894-95	.....	.75	.18	3.67	1.60	1.32	1.95	.78	.62	0.00	0.00	0.00	10.87
1895-96	.05	0.00	.34	.32	2.89	.06	1.21	2.82	.02	0.00	.07	.15	7.93
1896-97	.06	1.28	1.46	1.00	1.93	2.65	1.64	.30	0.00	T.	0.00	T.	10.32
1897-98	T.	1.19	.22	.48	.42	1.14	.71	0.00	.79	0.00	0.00	0.00	4.95
1898-99	1.12	.03	.34	.43	1.92	.02	2.90	.36	.06	.66	0.00	0.00	7.84
1899-1900	0.00	2.01	1.51	1.09	1.52	.08	.88	1.21	1.97	T.	T.	0.00	10.27

SACRAMENTO, CAL.

[Elevation, 71 feet; observers, Dr. Thomas M. Logan, Central Pacific Railroad Company, and United States Signal Service.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June.	July.	Aug.	Total.
1849-50	0.25	1.50	2.25	12.50	4.50	0.50	10.00	4.25	0.25	0.00	0.00	0.00	36.00
1850-51	0.00	0.00	T.	T.	.65	.35	1.88	1.14	.69	0.00	0.00	0.00	4.71
1851-52	1.00	.18	2.14	7.07	.58	.12	6.40	.19	.30	0.00	0.00	0.00	17.98
1852-53	T.	0.00	6.00	13.41	3.00	2.00	7.00	3.50	1.45	T.	T.	0.00	36.36
1853-54	T.	T.	1.50	1.54	3.25	8.50	3.25	1.50	.21	.31	0.00	T.	20.06
1854-55	T.	1.01	.65	1.15	2.67	3.46	4.20	4.32	1.15	.01	0.00	0.00	18.62
1855-56	T.	0.00	.75	2.00	4.92	.69	1.40	2.13	1.84	.03	0.00	0.00	13.76
1856-57	T.	.20	.65	2.40	1.38	4.80	.68	T.	T.	.35	.01	T.	10.47
1857-58	0.00	.66	2.41	2.63	2.44	2.46	2.88	1.21	.20	.10	0.00	T.	14.99
1858-59	T.	3.01	.15	4.34	.96	3.91	1.64	.98	1.04	0.00	.03	0.00	16.06
1859-60	.03	0.00	6.49	1.83	2.31	.93	5.11	2.87	2.49	.02	.55	0.00	22.63
1860-61	.06	.91	.18	4.28	2.67	2.92	3.32	.48	.59	.14	0.00	0.00	15.55
1861-62	0.00	T.	2.17	8.64	15.04	4.26	2.80	.82	1.81	.01	0.00	.01	35.56
1862-63	0.00	.36	.01	2.33	1.73	2.75	2.36	1.69	.36	0.00	T.	T.	11.59
1863-64	T.	0.00	1.49	1.82	1.08	.19	1.30	1.08	.74	.09	0.00	.08	7.87
1864-65	T.	.12	6.72	7.87	4.78	.71	.48	1.37	.46	0.00	T.	0.00	22.51
1865-66	.01	.48	2.43	.36	7.70	2.01	2.02	.48	2.25	.10	.02	0.00	17.86
1866-67	T.	T.	2.43	9.51	3.44	7.10	1.01	1.80	.01	0.00	0.00	0.00	25.30
1867-68	.01	0.00	3.81	12.85	6.04	3.15	4.35	2.31	.27	T.	0.00	0.00	32.78
1868-69	0.00	0.00	.77	2.61	4.79	3.63	2.94	1.24	.65	.01	0.00	0.00	16.64
1869-70	T.	2.12	.85	1.96	1.37	3.24	1.64	2.12	.27	T.	T.	T.	13.57
1870-71	0.00	.02	.58	.97	2.08	1.92	.69	1.45	.76	T.	0.00	0.00	8.47
1871-72	T.	.21	1.22	10.59	4.04	4.74	1.94	.61	.28	.02	0.00	0.00	23.65
1872-73	T.	.22	1.93	5.39	1.23	4.36	.55	.51	0.00	T.	.02	T.	14.21
1873-74	0.00	.31	1.87	10.12	5.30	1.86	3.05	.89	.37	0.00	0.00	0.00	23.77
1874-75	.05	2.26	3.80	.44	8.81	.03	1.26	0.00	.04	1.06	0.00	0.00	17.75
1875-76	0.00	.04	6.20	5.52	4.99	3.75	4.15	1.10	.15	0.00	.21	.02	26.13
1876-77	0.00	3.45	.30	0.00	2.77	1.04	.56	.19	.64	0.00	0.00	0.00	8.95
1877-78	0.00	.73	1.07	1.43	9.26	8.04	3.09	1.07	.17	0.00	0.00	0.00	24.86
1878-79	.29	.55	.51	.47	3.18	3.88	4.88	2.66	1.30	.13	T.	T.	17.85
1879-80	0.00	.88	2.05	3.41	1.64	1.83	1.70	14.20	.76	0.00	T.	T.	26.47
1880-81	0.00	0.00	.05	11.81	6.14	5.06	1.37	1.64	T.	.50	T.	T.	26.57
1881-82	.30	.55	1.88	3.27	1.89	2.40	3.78	1.99	.35	.10	T.	T.	16.51
1882-83	.57	2.63	3.22	1.13	2.23	1.11	3.70	.67	2.85	0.00	0.00	0.00	18.11
1883-84	.90	.97	.61	.44	3.43	4.46	8.14	4.32	1.16	1.45	0.00	0.00	25.88
1884-85	.60	2.01	0.00	10.45	2.16	.49	.08	.68	T.	.11	T.	0.00	16.58
1885-86	.08	.02	11.34	5.76	7.95	.29	2.68	4.08	.07	0.00	0.00	0.00	32.27
1886-87	0.00	.68	.21	2.21	1.12	6.28	.94	2.53	T.	0.00	0.00	T.	13.97
1887-88	.02	0.00	.45	2.09	4.81	.57	3.04	.10	.40	.08	T.	T.	11.56

A. RED MOUNTAIN GAGING STATION ON KINGS RIVER.

B. FALLS IN CREEK ABOVE EAST LAKE.

Annual precipitation in inches—Continued.

SACRAMENTO, CAL.—Continued.

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1888-89	0.55	0.00	4.28	4.63	0.15	0.33	6.25	0.26	3.25	0.25	0.00	0.00	19.95
1889-90	0.00	6.02	3.15	7.82	6.62	4.06	3.00	1.33	1.80	0.00	0.00	T.	33.80
1890-91	.80	T.	0.00	3.34	.53	6.61	1.78	2.04	.66	.05	T.	0 00	15.81
1891-92	.10	.10	.48	3.28	1.78	2.84	3.02	1.20	2.38	T.	0.00	0.00	15.18
1892-93	.18	.70	6.60	4.90	3.27	2.66	3.51	1.08	1.05	0.00	T.	0.00	23.95
1893-94	.22	.12	2.92	1.76	4.17	3.92	.74	.34	1.70	.46	T.	T.	16.35
1894-95	.88	1.06	.48	8.86	8.42	1.84	1.20	.86	.51	0.00	.04	T.	24.15
1895-96	1.26	.17	1.54	1.54	9.76	.09	2.57	5.34	.92	0.00	T.	.20	23.39
1896-97	.31	.55	3.56	1.76	3.66	4.15	2.54	.25	.30	.04	0.00	0.00	17.12
1897-98	.16	1.96	.61	1.64	.98	3.19	.04	.28	1.50	.14	0.00	0.00	10.50
1898-99	.36	.64	.61	2.30	3.94	.04	6.02	.10	.54	.49	0.00	.02	15.06
1899-1900	0.00	4.46	2.62	2.91	3.54	.32	1.61	1.88	2.88	T.	T.	0.00	20.22

T indicates trace.

No rainfall records of extended duration have been maintained in the higher portion of the drainage basin. A few miles to the north, on the same slope, at Summerdale, the record from 1896 to 1899 shows an average of 47.86 inches. At Sequoia, on the same range and slope, 50 miles to the north, the average for three years, from 1897 to 1900, was 46.90 inches, the elevation being 4,452 feet. At Second Garrotte, about 60 miles to the northwest, on the same slope of the Sierra, a thirteen-year record shows an average rainfall of 38.98 inches, the elevation being 2,900 feet.

The rainy season in California extends from about the first of October until about the first of April. The maximum monthly precipitation probably occurs during the month of January. In the foothills and valleys there is practically no rainfall during the summer. In the mountains above 10,000 feet in elevation, however, frequent thunderstorms occur in the afternoons, particularly during the months of July and August. The rainfall on the western slope of the sierras, in the basin of the Tuolumne, increases at the rate of about 0.8 inch per 100 feet until an elevation of approximately 7,000 feet is reached, beyond which there probably is no increase, though data bearing on the subject are meager. The mean annual rainfall for the basin is probably about 40 inches and the stream run-off about 40 per cent of the rainfall.

REGIMEN OF RIVER.

The period of minimum flow of the streams is in September and October. The rains falling in the foothills in the late autumn increase somewhat the fall discharge of the river, but the heavier precipitation on the higher mountains is retained until melted during the following summer. The river gradually increases in volume after the first of February, in normal years usually reaching a maximum between May 20 and June 10. This spring water comes from the melting of the great snow banks above the 4,000-foot contour. Probably the greatest floods that occur in this drainage basin are brought about by warm spring rains falling upon the snow in the foothills. During mid

summer the flow of the river is maintained mostly from the melting of the snow banks and small glaciers near the crest. These never entirely disappear. It is probable that during the mid and late summer period there is a greater volume of water in the drainage lines at the 3,000- or 4,000-foot contour than there is in the main stream at the mouth of the canyon, as the lower elevations of the drainage basin do not then contribute materially to the flow, and considerable loss by evaporation occurs in the lower reaches of the river.

In November, 1878, the California State engineering department began measurements of the discharge of Kings River at the base of the foothills and continued them until October, 1883. The point of measurement was above all diversions by the canals and shows the total discharge of the stream.[a] The results of these measurements are given in the following tables:

Estimated monthly discharge of Kings River at Slate Point, Cal.

[Drainage area, 1,742 square miles.]

Month.	Mean discharge in second-feet.	Total for month in acre-feet.	Run-off.	
			Depth in inches.	Second-feet per square mile.
1878-79.				
November	300	17,851	0.19	0.17
December	290	17,831	.18	.16
January	370	22,750	.24	.21
February	870	48,317	.52	.50
March	1,970	121,130	1.30	1.13
April	4,750	282,645	3.03	2.72
May	5,090	312,972	3.37	2.92
June	3,760	223,736	2.40	2.15
July	1,650	101,455	1.08	.94
August	380	23,366	.25	.22
September	770	16,066	.16	.14
October	280	17,217	.18	.16
The year	1,665	1,205,336	12.90	.95
1879-80.				
November	400	23,802	.26	.23
December	1,440	88,542	.94	.82
January	720	44,271	.47	.41
February	1,040	60,396	.65	.60
March	1,120	68,866	.74	.64
April	5,230	311,207	3.30	3.00
May	7,120	437,792	4.63	4.01
June	9,540	567,669	6.06	5.41
July	4,800	295,141	2.44	2.11
August	1,150	70,711	.76	.66
September	370	22,017	.23	.21
October	220	13,527	.15	.13
The year	2,768	2,008,941	20.63	1.52
1880-81.				
November	220	13,091	.13	.12
December	510	31,359	.33	.29
January	870	53,494	.58	.50
February	2,430	134,955	1.45	1.39
March	1,900	106,876	1.26	1.09
April	5,800	345,174	3.71	3.33
May	8,220	505,428	5.44	4.71
June	5,010	298,116	3.21	2.88
July	4,790	294,526	3.17	2.75
August	650	39,967	.43	.37
September	340	20,231	.21	.19
October	250	15,372	.16	.14
The year	2,583	1,858,489	20.08	1.48

[a] Physical Data and Statistics of California, p. 452.

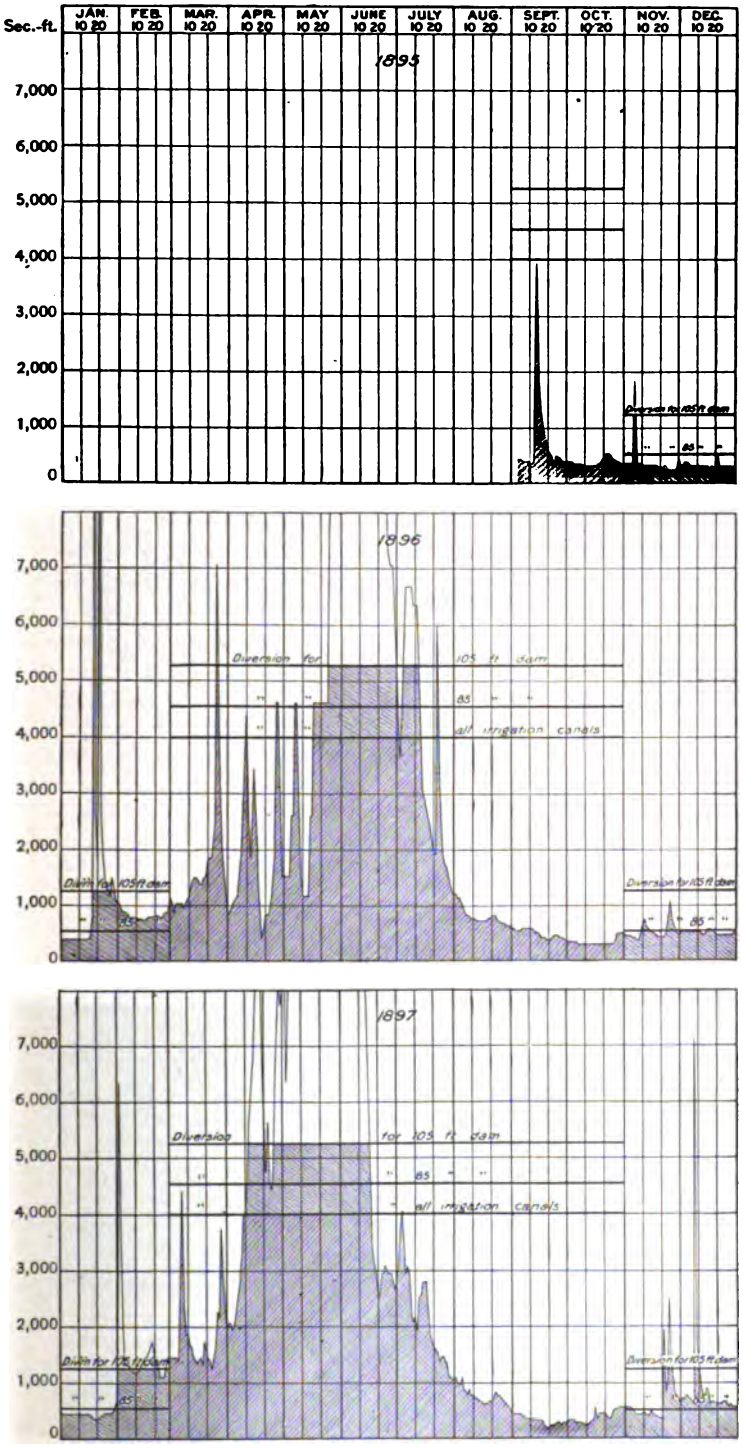


DIAGRAM SHOWING DISCHARGE OF KINGS RIVER AT RED MOUNTAIN GAGING STATION FOR YEARS 1895 TO 1897.

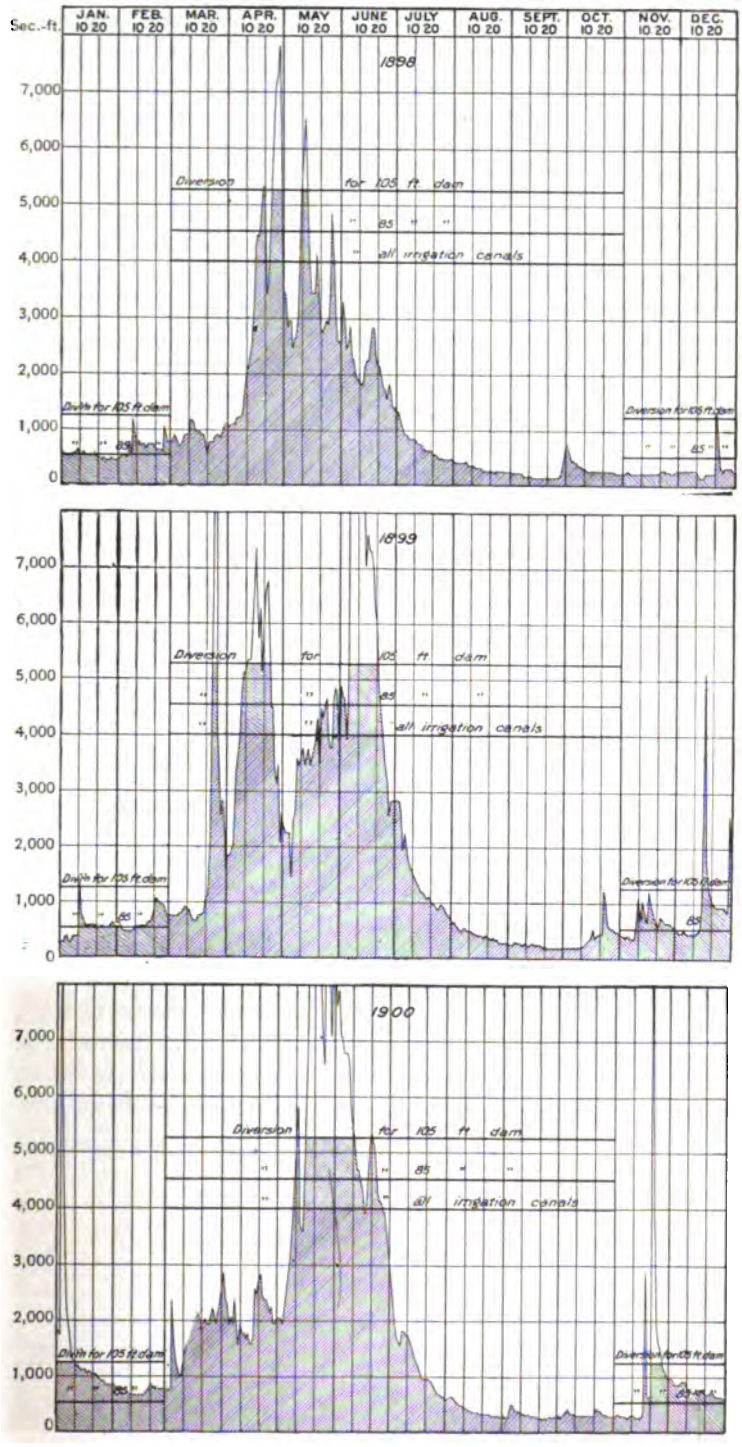


DIAGRAM SHOWING DISCHARGE OF KINGS RIVER AT RED MOUNTAIN GAGING STATION FOR YEARS 1898 TO 1900.

Estimated monthly discharge of Kings River at Slate Point, Cal.—Continued.

Month.	Mean discharge in second-feet.	Total for month in acre-feet.	Run-off.	
			Depth in inches.	Second-feet per square mile.
1881-82.				
November	230	13,686	0.14	0.13
December	260	15,987	.17	.15
January	380	23,366	.25	.22
February	440	24,436	.26	.25
March	1,250	76,859	.83	.72
April	3,170	188,628	2.03	1.82
May	9,190	565,071	6.12	5.28
June	6,410	381,421	4.10	3.68
July	2,020	124,205	1.34	1.16
August	620	38,122	.41	.36
September	390	23,207	.24	.22
October	610	37,507	.40	.35
The year	2,081	1,512,495	16.29	1.20
1882-83.				
November	470	27,967	.30	.27
December	340	20,906	.22	.19
January	320	19,676	.21	.18
February	340	18,883	.22	.19
March	1,050	64,562	.69	.60
April	2,220	132,099	1.42	1.27
May	6,700	411,967	4.48	3.85
June	6,730	400,463	4.10	3.68
July	1,460	89,772	.97	.84
August	600	36,898	.39	.34
September	480	28,562	.30	.27
October	420	25,825	.28	.24
The year	1,761	1,277,575	13.58	.99

Since September, 1895, the United States Geological Survey has made measurements of the total flow of Kings River above the diversion of all canals. The point of observation is known as Red Mountain. (See Pl. VI, *A*.) It is 3 or 4 miles above the mouth of the canyon and within a mile of the proposed point of diversion of Kings River to the Clarks Valley reservoir, described further on. The data showing the daily fluctuation of the river as measured by the California State engineering department are not available, but the aggregate monthly and seasonal discharge for the years given by the State engineer show greater volume than the aggregate discharge as measured by the Geological Survey for the minimum year—1898. The record kept by the Geological Survey is given in the following tables and is shown graphically in the diagrams forming Pls. VII and VIII:

Estimated monthly discharge of Kings River at Red Mountain, Cal.

[Drainage area, 1,742 square miles.]

Month.	Discharge in second-feet.			Total for month in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1895.						
September	3,920	360	778.0	46,294	0.50	0.45
October	520	320	371.0	22,812	.24	.21
November	1,834	250	368.0	21,898	.23	.21
December	520	250	328.0	20,168	.22	.19
Four months	3,920	250	461.0	111,172	1.19	.27

Estimated monthly discharge of Kings River at Red Mountain, Cal.—Continued.

Month.	Discharge in second-feet.			Total for month in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1896.						
January	11,020	390	1,474.8	90,682	0.98	0.85
February	1,140	728	825.4	47,477	.51	.47
March	7,020	820	1,710.6	105,181	1.13	.98
April	4,600	390	1,938.5	115,349	1.24	1.11
May	22,100	1,140	5,918.1	363,890	3.90	3.40
June	18,920	5,160	12,737.3	757,922	8.15	7.31
July	6,680	1,212	3,742.2	230,110	2.48	2.15
August	1,212	590	759.9	48,938	.52	.45
September	590	390	491.3	29,234	.31	.28
October	510	310	350.0	21,520	.23	.20
November	1,076	390	538.5	32,043	.35	.31
December	550	470	498.4	30,645	.33	.29
The year	22,100	310	2,585.1	1,872,991	20.13	1.48
1897.						
January	624	360	437.0	26,870	.29	.25
February	6,344	1,100	1,631.0	90,581	.96	.92
March	4,408	1,240	1,884.0	115,843	1.22	1.06
April	9,380	1,930	5,318.0	316,442	3.33	2.99
May	22,732	6,344	14,470.0	889,731	9.40	8.15
June	10,580	2,520	6,145.0	365,652	3.87	3.45
July	4,040	1,036	2,177.0	133,859	1.41	1.22
August	1,100	440	739.0	45,440	.47	.42
September	480	250	329.0	19,577	.20	.18
October	572	270	394.0	24,226	.25	.22
November	2,520	360	692.0	41,177	.44	.39
December	8,348	572	985.0	60,566	.63	.55
The year	22,732	250	2,933.0	2,129,964	22.47	1.65
1898.						
January	624	440	506.0	31,113	.33	.29
February	1,170	480	705.0	39,154	.41	.40
March	1,170	520	895.0	55,032	.58	.50
April	7,820	1,036	3,547.0	211,061	2.23	2.00
May	6,520	2,450	3,536.0	217,422	2.29	1.99
June	3,280	1,310	2,122.0	126,267	1.34	1.20
July	1,310	440	696.0	42,796	.45	.39
August	400	215	320.0	19,676	.21	.18
September	780	145	204.0	12,139	.13	.12
October	728	215	320.0	19,676	.21	.18
November	285	215	231.0	13,745	.14	.13
December	1,450	180	315.0	19,369	.21	.18
The year	7,820	145	1,116.0	807,450	8.53	.63
1899.						
January	1,310	250	513.0	31,543	.33	.29
February	1,036	440	660.0	36,655	.39	.37
March	20,200	624	2,165.0	133,121	1.41	1.22
April	7,300	1,834	4,512.0	268,483	2.83	2.54
May	4,780	1,450	3,568.0	219,388	2.32	2.01
June	10,300	2,852	6,077.0	361,607	3.81	3.42
July	2,852	676	1,411.0	86,759	.91	.79
August	624	250	411.0	25,271	.26	.23
September	285	180	215.0	12,793	.13	.12
October	1,205	180	378.0	23,242	.24	.21
November	1,240	345	638.0	37,964	.40	.36
December	5,096	400	991.0	60,934	.64	.56
The year	20,200	180	1,795.0	1,297,760	13.67	1.01
1900.						
January	12,700	849	1,689.0	103,853	1.12	.97
February	849	676	748.0	41,542	.45	.43
March	2,584	728	1,712.0	105,267	1.13	.98
April	2,852	1,546	2,098.0	124,840	1.34	1.20
May	9,400	1,930	5,881.0	361,609	3.90	3.38
June	7,900	2,986	5,127.0	305,078	3.27	2.94
July	2,584	572	1,278.0	78,581	.84	.73
August	624	250	398.0	24,472	.26	.23
September	520	215	301.0	17,911	.19	.17
October	440	215	309.0	19,000	.21	.18
November	15,700	250	1,310.0	77,950	.83	.75
December	972	572	726.0	44,640	.48	.42
The year	15,700	215	1,798.0	1,304,743	14.02	1.03

The last five years, during which records have been kept by the Geological Survey, have been years of relative drought in California, as will be seen by the Fresno rainfall records (page 16), which are continuous since 1877. The twenty-three-year mean at Fresno is 8.79 inches, and that of the last five years is 8.26 inches. The precipitation during the winter of 1897–98 was within 0.08 inch of the smallest ever recorded. It is believed that the records of the Geological Survey represent a minimum annual flow of the river, and that estimates based upon them will be conservative.

Perhaps once in ten years seasons of extremely low discharge may occur, when there may be a shortage of water for the systems contemplated in this report, but it is believed that the shortage will not be great enough to be seriously detrimental to the interests depending upon the water supply for either storage or power. It would hardly seem to be necessary, or good engineering, to plan works for a minimum flow, which probably will not occur more than once in ten years, if during the minimum year 80 or 90 per cent of the water supply needed be available. A notable case in point is the Sweetwater reservoir, which was entirely dry during the season of 1899–1900, yet by continued cultivation of the orchards and the use of temporary pumping plants a good crop was harvested from a very reduced supply of water. It may be stated that Kings River, which drains 1,742 square miles of the western slopes of the Sierra Nevada, from banks of perpetual snow and from some of the finest forests of the State, can be relied upon for a great water supply. It is one of the largest streams in the State from which water is obtained for irrigation purposes.

The following is a general summary of the total volume of the river. The figures for the first five years are from the records of the State engineering department, those for the last five years are from the records of the Geological Survey.

Annual discharge of Kings River.

	Acre-feet.
1878–79	1,205,336
1879–80	2,003,941
1880–81	1,858,489
1881–82	1,512,495
1882–83	1,277,575
Five-year mean	1,571,567
1896	1,872,991
1897	2,129,964
1898	807,450
1899	1,297,760
1900	1,304,838
Five-year mean	1,482,601

The available supply from the river is discussed further in connection with the Pine Flat reservoir site (pages 30 to 33) and the Clarks Valley reservoir site (pages 39 to 42).

EVAPORATION AND SEEPAGE.

Evaporation observations were made by the State engineering department of California from November, 1881, to October, 1885, inclusive, at Kingsburg, on Kings River, at an elevation of 297 feet above sea and 20 miles southwest from the proposed Clarks Valley reservoir site. The results of these observations are given in the following table. A pan was floated in the river and observations were made daily thereon, the pan being kept at practically the same temperature as the water in the stream. The total mean annual evaporation observed was 3.851 feet.

Evaporation at Kingsburg, on Kings River.[a]

[Elevation, 297 feet.]

Month.	Depth in feet.			
	1881-82.	1882-83.	1883-84.	1884-85.
November	0.220	0.115	0.170	0.200
December	.050	.085	.080	.180
January	.090	.060	.105	.010
February	.115	.100	.050	.140
March	.180	.305	.090	.240
April	.260	.270	.160	.160
May	.305	.160	.320	.340
June	.475	.500	.295	.660
July	.660	.760	.380	.710
August	.665	.920	.370	.930
September	.475	.730	.320	.640
October	.135	.400	.350	.470
The year	3.630	4.405	2.690	4.680

[a] Physical Data and Statistics of California, p. 378.

The amount of water lost by seepage and evaporation by the Kings River canals was made the subject of careful study by C. E. Grunsky, for the California State engineering department, in the summer of 1882, the results of which are given in Water-Supply and Irrigation Paper of the United States Geological Survey No. 18, page 74. The actual loss by evaporation from the surface of the water while in transit in the canals is very small; probably 1 per cent would cover it. The greater loss is occasioned by seepage. The canals of this district are not all built on true grades, and some of them have swamps and pools along their courses. In one instance—on the Centerville and Kingsburg canal—a loss of 52 second-feet was shown in 1 mile. The observations by Mr. Grunsky were made nearly twenty years ago, when the water plane was not so near the surface as it now is, and consequently the seepage losses were greater than now. The general

result of his observations shows a loss of 307.11 second-feet in 50.8 miles out of a total diversion of 860.83 second-feet. This amounts to 6.05 second-feet to the mile, or 36 per cent of the total diversion. The measurements on the river and on the Fresno canal were made from about a half mile to 20.3 miles below its head, and showed a loss of 64.3 second-feet out of 133.83 second-feet diverted. On the Fresno canal the loss from about 1¼ to 23½ miles below the headworks was 104.52 second-feet out of 381 second-feet diverted. On the Centerville and Kingsburg canal, from a half mile to 7 miles from the headworks, the loss was 138.29 second-feet out of 346 second-feet diverted. Relatively, the greater rate of loss in the canals was in the first few miles from the headworks, where they are in porous soils, close together, and approximately parallel.

The loss of water from a canal by seepage is governed by the rate of percolation, the area through which percolation occurs, and the period of time during which a given unit of water is exposed. The greater the depth of water in a canal the greater the velocity of flow, and consequently the less time is a given unit of water exposed to loss by percolation in any section of the canal. This increase of velocity due to greater depth is relatively larger than the increase of wetted area through which percolation takes place. For instance, if an earthen canal 40 feet wide has a slope of 5.28 feet to the mile and a depth of water of 2 feet it would discharge 220 second-feet with a velocity of 2.74 feet per second. With other conditions the same, if the depth of water were increased to 4 feet the discharge would be 670 second-feet with a velocity of 4.19 feet per second. Thus, while the wetted area exposed to percolation increases 9 per cent the discharge trebles. For the sake of comparison, suppose the velocity of percolation were 0.10 foot per hour. Then in the canal flowing 2 feet deep the loss per second per lineal foot of canal would be 0.00122 second-foot, and with the canal flowing water 4 feet in depth it would be 0.00133 second-foot. Comparing this loss with the respective volumes carried by the two canals, we find that the relative loss of water in the large canal is but 40 per cent of that in the small canal.

If the three canals referred to had been consolidated and all water run through the Kings River and Fresno canal, then using Mr. Grunsky's data and the foregoing reasoning it would be safe to say that in the first 11¼ miles of the Fresno canal 95.51 second-feet would have been saved, and in the first 6.5 miles of the Centerville and Kingsburg canal 138.29 second-feet would have been saved, or 233.80 second-feet out of a total loss of 307.11 second-feet. This would reduce the loss to 8.5 per cent of the whole, instead of 36 per cent, which Mr. Grunsky found.

It must be remembered, however, that the losses described occurred in 50.8 miles of main canals, during the early stages of irrigation

development, and that probably there would be on an average as much more lost in the distribution laterals. Enough data are not at hand to draw accurate conclusions, but it is believed that under favorable conditions fully 25 per cent of the river water would be lost in reaching the land to be irrigated.

If water be drawn from reservoirs to supplement the low-water supply of the canals it will be water added to most of the canals and not subject to so heavy a rate of loss as, say, 25 per cent of the water first diverted; probably 15 per cent would be nearer the actual amount.[a]

RECONNAISSANCE OF BASIN.

In the investigation of the large basin of Kings River, which from a hydrographic point of view was practically unknown, it was decided to equip two parties for the season's work. Accordingly a reconnaissance party was organized and placed in charge of Mr. E. G. Hamilton, topographer from the United States Geological Survey. The work of this party was largely exploratory, but at the close of the season the Clarks Valley reservoir site was surveyed by Mr. Hamilton. The reconnaissance party was instructed to visit all portions of the drainage basin, make instrumental examinations of all possible reservoir sites, and at the end of each month report the character of the sites found. A second party was organized, under the direction of Mr. H. E. Green, an engineer of extended experience in the construction of storage reservoirs, for the purpose of making more detailed surveys of the better sites found by the exploration party. The reconnaissance party reported upon and sketched seven reservoir sites, four of which were surveyed under the direction of Mr. Green.

The following instructions were given to the engineers for their guidance in making reports:

Report on reservoir survey.

(1) Give name of engineer in charge and date of survey.
(2) Name of locality.
(3) Streams tributary to site.
(4) Land title to site.
(5) If possible tie reservoir surveys to land surveys. The point of reservoir survey to be tied in is preferably the ends of the dam.
(6) If the land is not subdivided, tie reservoir survey to prominent natural objects.
(7) Estimate area of tributary drainage basin.
(8) Give general statement of elevation of drainage basin and elevation of reservoir site.
(9) State whether drainage basin is timbered or bare hills.
(10) Compute water supply.
(11) Give capacity of reservoir with various heights of dam.
(12) State character of material for dam; earth, rock fill, or concrete.

[a] See addenda on page 99.

(13) For purposes of preliminary estimate consider—
Earthen dam 20 feet wide on top; 2½ to 1 slope on inner face, 1½ to 1 on outer face. Describe the quality of the available earth, which should be a clay, sand, and rock, also give length of haul.
Rock-fill dam 20 feet wide on top; 1½ to 1 outer slope, 1 to 1 inner slope. State position of available rock supply, give probable cost of cement delivered on the ground, and available timber for inner face and cost thereof.
Concrete dam. State the proximity and relative elevation of quarries, and the cost per barrel of cement delivered on the ground.
(14) Report on probable foundations for dam.
(15) Estimate on the cost of dam.
(16) State cost per acre-foot of water stored.*

The requisites of a reservoir site are numerous and exacting, as follows:

(1) There must be an available water supply sufficient to fill the basin.
(2) There must be a basin to hold this supply.
(3) There must be a good dam site.
(4) There must be good materials of which to make a dam.
(5) The foundations must be able to sustain the dam.
(6) There must be available lands upon which to put the water.
(7) The entire project must be on a commercial basis.

There are a large number of sites on the river which were popularly supposed to be good but which proved to be objectionable, owing to the lack of some one of the foregoing vital requisites.

The field party, which consisted of a topographer, a rodman, and a cook, left Sanger, in Fresno County, a station on the Southern Pacific Railroad at an elevation of 370 feet, on May 22, 1900. The route of travel is shown on the map, Pl. I, which was furnished by Mr. J. N. Le Conte for use in connection with this report.

The first site investigated was the upper Clarks Valley, 16 miles east of Sanger, 10 miles north of Reedley, and 1 mile north of where the stage road from Sanger to Millwood crosses Wahtoke Creek; elevation, 500 feet. This site is at the upper end of the main Clarks Valley reservoir site, and is included by it. It is shown on the map of the Clarks Valley site (Pl. XIII), and is not estimated upon separately.

From Clarks Valley the party went back to Kings River, and following along its east bank to the mouth of Mill Creek ascended that creek 4 miles, to McHaley's ranch, at an elevation of 650 feet. A half mile above McHaley's ranch a reservoir site was surveyed, and it was found that a concrete dam 195 feet in height would store 3,500 acre-feet of water at a cost of $130 per acre-foot, which of course is prohibitive.

After spending two days in the hills between Mill Creek and Kings River the party went by trail from McHaley's ranch to Squaw Valley, then along the Millwood stage road to Dunlap. At Dunlap a stay of

*An acre-foot of water is an amount sufficient to cover 1 acre to a depth of 1 foot.

three days was made to permit an investigation of the drainage of Mill Creek. After leaving Dunlap the party followed the stage road to Millwood, then took the trail through the General Grant National Park to Huckleberry Meadow, a small meadow 8 miles northeast of Millwood and at an elevation of 6,000 feet. With Huckleberry Meadow as a base of supplies, trips were made to the meadows and basins within a radius of 20 miles. The largest of these meadows are Converse Basin, 10 miles northwesterly from Huckleberry Meadow; Bearskin Meadow, 6 miles to the east; Burton Meadow, 10 miles to the east; Squawskin Meadow, 14 miles to the east; and Big Meadows, 16 miles to the south. Big Meadows is the only one of these reservoir sites that has a good dam site, but as it is on the divide between Kings and Kaweah rivers and has only 8 square miles of watershed it was not mapped. The Long Meadow reservoir site, which is in this locality, was surveyed by Mr. Green, and the results of the survey are given on pages 44 to 46.

SOUTH FORK.

There are two trails leading from Huckleberry Meadow to the grand canyon of Kings River. The upper trail is the shorter and better, but there is no bridge across Boulder Creek and it is dangerous to attempt to ford it during high water. On the lower trail, however, there is a bridge, which made it possible to move the camp from Huckleberry Meadow to the grand canyon of the Kings, where two sites were surveyed, one with the dam site a half mile below the junction of Copper Creek and the South Fork of Kings River, in sec. 14, T. 13 S., R. 31 E., Mount Diablo base and meridian, at an elevation of 5,000 feet; the other, 5 miles farther down the South Fork of Kings River, with the dam site a half mile below the mouth of Lewis Creek, in sec. 10, T. 13 S., R. 30 E., at an elevation of 4,300 feet.

At either of these sites it would be necessary to construct an overflow dam on the South Fork. A 210-foot dam at the site below the mouth of Copper Creek would store approximately 29,378 acre-feet of water. The estimated cost of storage is about $67 per acre-foot for a rubble masonry dam. A 200-foot dam at the lower site would store 14,100 acre-feet, and the estimated cost of storage is $178 per acre-foot. These dams would have to be made of hydraulic-cement masonry. In both of these cases the excessive cost per acre-foot stored renders the construction of the dams impracticable.

A view in the canyon of the South Fork near the mouth of Copper Creek is shown in Pl. IX.

From the site at the mouth of Lewis Creek the bed of the South Fork down to its junction with the Middle Fork is narrow and has a heavy grade.

CLIFFS ON SOUTH FORK OF KINGS RIVER.

BUBBS CREEK AND HEADWATERS OF SOUTH FORK.

The channels of both of these streams are narrow, averaging from 500 to 1,000 feet in width, with high granite walls on either side, and with a fall of from 50 to 200 feet to the mile. Near their headwaters are numerous small lakes, one of which, Lake Charlotte, was mapped. (See fig. 1.) This lake is on the headwaters of Bubbs Creek, near the divide between that stream and the South Fork of Kings River, at an elevation of 10,500 feet, and has a drainage area of about 8 square miles. The surface area of the lake is 24 acres and the depth of the water about 30 feet. Owing to its inaccessibility and to the lack of a good dam site it was not considered as a possible storage basin.

Pl. VI, *B*, is a view of the falls in a creek above East Lake in the South Fork drainage.

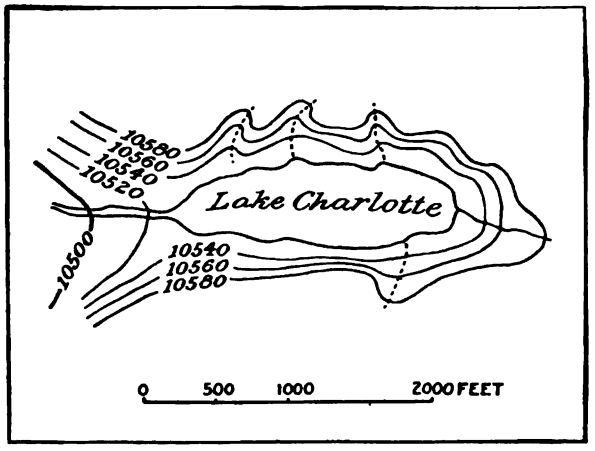


FIG. 1.—Lake Charlotte reservoir site.

PARADISE VALLEY.

Paradise Valley, on the South Fork of Kings River, 5 miles above the mouth of Bubbs Creek and at an elevation of 6,500 feet, was explored, but its floor, although in places 2,000 feet wide, has a fall of 40 feet in 1,000 feet, and it therefore is not a good reservoir site. It is also inaccessible.

ROARING RIVER AND SUGARLOAF CREEK.

Near the headwaters of these streams are numerous small meadows, but not one that was visited has a good dam site. The channels of the main streams are narrow gorges with falls or slopes varying from 50 feet to 500 feet to the mile. Leaving the South Fork of Kings River the third week in July, the party started for Simpson Meadows, on the Middle Fork, spending several days in reconnaissance en route, but with one exception (Granite Basin) no reservoir sites of any value were found. The Granite Basin site was examined by Mr. Green, the results of the examination being given on page 48.

SIMPSON MEADOWS.

The Simpson Meadows, on the Middle Fork of Kings River at an elevation of 6,000 feet, have an average width of 3,000 feet. The larger part of the meadows is on the east side of the river, and extends a mile above the mouth of Goddard Creek and 3 miles below it. A dam 200 feet in height would be required to flood the meadows. Its top length would be 3,000 feet, and the cost would be so great as to make it prohibitive. While camped in Simpson Meadows the party spent several days in exploring Cartridge, Palisade, Goddard, and Disappearing creeks and the headwaters of the Middle Fork, but found no storage basins of value.

Leaving Simpson Meadows the second week in August the party followed the Tunema and Collins trail to Cliff Camp, on the North Fork of the river. (See Pl. X.) Between the Middle and North forks are numerous small meadows, most of them near the summits of the ridges, with from 3 to 5 square miles of watershed, but not one of them has a good dam site or an extensive drainage basin.

DUSY MEADOWS.

On the North Fork two reservoir sites were mapped—the Dusy Meadows site and one three-fourths of a mile farther upstream. At the latter site, which is the smaller of the two, a concrete overflow dam 150 feet high would store 5,440 acre-feet of water, but at a prohibitive cost—about $276 per acre-foot stored.

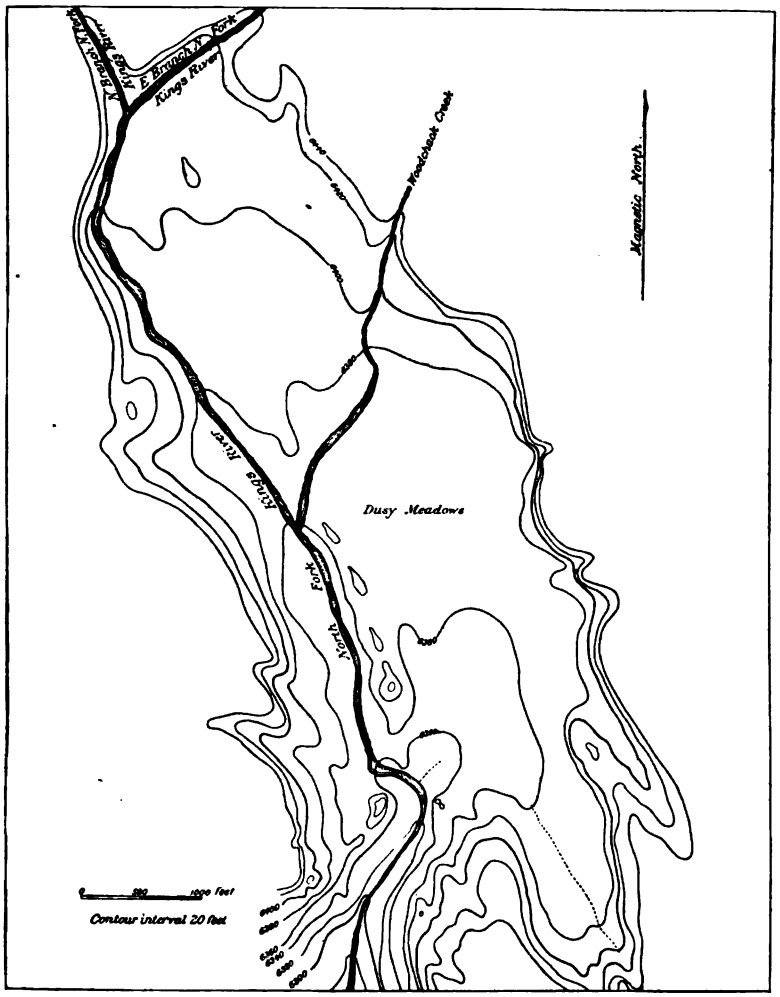
The Dusy Meadows reservoir site is in Fresno County, on the North Fork of Kings River, in sec. 36, T. 10 S., R. 27 E., and sec. 31, T. 10 S., R. 28 E., Mount Diablo base and meridian. The drainage area of the basin of the North Fork above the reservoir site is 144 square miles, at an average elevation of 9,000 feet above sea level. Assuming the average annual rainfall to be 39 inches and 620 acre-feet the annual run-off per square mile, we have 88,280 acre-feet as the amount of water available for storage purposes from the drainage basin. The elevation of the dam site, as determined from aneroid measurements, is 6,300 feet above the sea, and the capacity of the reservoir at different heights of the water would be as follows:

Capacity of Dusy Meadows reservoir site.

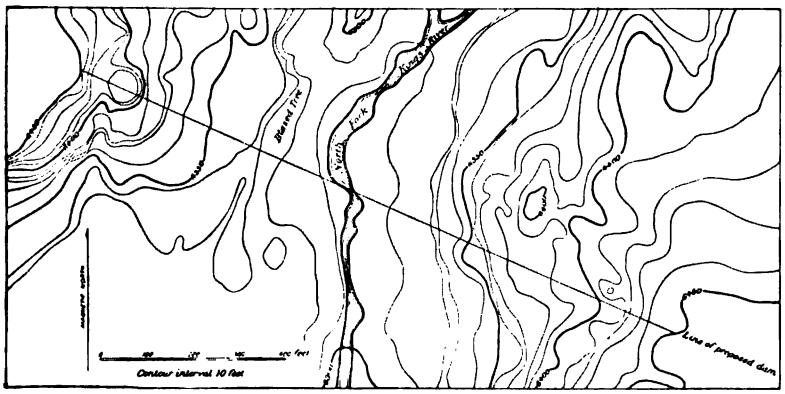
	Acre-feet.
Between 20- and 40-foot levels	180
Between 40- and 60-foot levels	860
Between 60- and 80-foot levels	2,930
Between 80- and 100-foot levels	5,460
Between 100- and 120-foot levels	7,420
Total	16,850

The reservoir site is mapped in Pl. XI, *A*, and the dam site in Pl. XI, *B*. A loose rock dam 125 feet in height, faced with timber, is

CLIFF CAMP, ON NORTH FORK OF KINGS RIVER, AT LOW-WATER STAGE OF STREAM.



A. CONTOUR MAP OF DUSY MEADOWS RESERVOIR SITE.



B. CONTOUR MAP OF DUSY MEADOWS DAM SITE.

estimated upon for this site. There is plenty of granite rock on both sides of the dam site which could readily be transported by cable or other mechanical devices, and there are at hand large quantities of standing timber, both yellow pine and fir.

In the following estimate of cost the quantities given are for a dam with slopes of ½ to 1 and 1 to 1, with a width of 20 feet on top, a plank face 6 inches thick, and sills 12 inches by 12 inches, with 12 feet between centers.

Estimate of cost of Dusy Meadows dam.

Rock, 378,000 cubic yards at $0.75	$283,500	
Planking for face, 656,000 feet, B. M., at $40	26,240	
Sills, 111,000 feet, B. M., at $40	4,440	
Labor in laying 767,000 feet, B. M., at $6	4,600	
		$318,780
Two spillways, one on each side of the dam, each having a capacity of 3,300 second-feet, 45,000 cubic yards of rock at $1		45,000
Arched outlet tunnel 4 feet by 6 feet by 400 feet long, cement lined, at $10 per lineal foot	$4,000	
Tower and gates	8,000	
Machinery, cables, etc	25,000	
		37,000
Building road from the end of the present road at Russel's camp to the dam site (20 miles) and about the works (2 miles), 22 miles at $3,000		66,000
Engineering expenses and contingencies		72,080
Total cost of dam		538,860

The total capacity of the reservoir being 16,850 acre-feet and the total cost of the dam $538,860, the cost per acre-foot stored would be $32.

DINKEY CREEK.

After leaving the North Fork the trail runs almost due west for 15 miles, to Russel's camp, on Dinkey Creek, through a flat, open country heavily timbered, mostly with fir, until within 3 miles of the creek, when the trail begins to descend from the 7,000-foot level to the 6,000-foot level, the sugarpine trees become more plentiful, and occasionally, in the beds of the streams, a few sequoias are seen. Dinkey Creek does not flow through any large basins or meadows. The average fall of the creek is from 25 to 75 feet in 1,000, except near the headwaters, where the bed is in solid, glaciated granite channels, with a fall of from 10 to 25 feet in 1,000.

From Russel's camp west to Ockenden, a distance of 15 miles, there is a road built to enable the lumbermen to haul sugarpine shingles to a market at Fresno. There is probably no place in California where there is more reckless destruction of timber than along this road. On either side of it hundreds of fine sugarpines have been cut. Trees 3 to 5 feet in diameter, with the lowest limbs 60 and 70 feet from the ground, have been felled to use perhaps from 6 to 9 feet of the base for shingles, leaving the rest of the timber to rot.

PINE FLAT.

After exploring the drainage basins of Big and Sycamore creeks the party made a detailed survey of the Pine Flat reservoir site (see Pl. XII), on the main Kings River, 5 miles below Trimmer, in secs. 12, 19, 24, 25, 26, 35, and 36, T. 12 S., R. 24 E., Mount Diablo base and meridian. The dam site is in section 35. The elevation at the base of the proposed dam is 600 feet. The bed rock is a blue slate, solid and bare in the creek bed but seamy on the east side.

The following estimates of the capacity and cost of the reservoir are only preliminary and approximate. Careful examinations should be made before construction is begun. A section of the proposed weir is shown in fig. 2.

Capacity of Pine Flat reservoir.

Height of dam.	Area.	Capacity between contours.	Total capacity.
Feet.	*Acres.*	*Acre-feet.*	*Acre-feet.*
0	0.0	.....	.....
20	57.2	572	572
40	187.0	2,442	3,014
60	372.3	5,593	8,607
80	568.7	9,410	18,017
100	912.7	14,814	32,831
120	1,125.0	20,377	53,208
140	1,373.9	24,989	78,197
160	1,642.9	30,168	108,365
180	1,902.4	35,453	143,818
200	2,174.0	40,764	184,582

Estimated cost of dam 200 feet in height.

485,000 cubic yards of rubble masonry at $7	$3,395,000
Concrete apron at lower toe of dam, 1,400 feet long, 60 feet wide, and 3 feet thick, 9,333 cubic yards at $9	84,000
Gates, outlet pipes, etc	50,000
Right of way	25,000
Engineering, 2½ per cent	88,850
Contingencies, 7½ per cent	266,550
Total	3,909,400

Estimated cost of dam 140 feet in height.

212,000 cubic yards of rubble masonry at $7	$1,484,000
Concrete apron at lower toe of dam, 1,100 feet long, 50 feet wide, and 3 feet thick, 6,111 cubic yards at $9	55,000
Gates, outlet pipes, etc	50,000
Right of way	25,000
Engineering	50,000
Contingencies	86,000
Total	1,750,000

The cost per acre-foot of water stored is $21.18 for the 200-foot dam and $22.38 for the 140-foot dam. In the case of the 140-foot dam, if the interest on the cost of the works be taken at 6 per cent, the taxes at eight-tenths of 1 per cent, and maintenance at $10,000 per annum, the annual charge for operation will be $129,000, or $1.65 for each acre-foot stored in the reservoir. If 20 per cent of the water

stored is lost by seepage and evaporation before reaching the lands to be irrigated, the annual charge per acre-foot delivered will be $2.06.

The estimates are for a dam made of large blocks of granite bedded in a hydraulic-cement mortar. It would be 16 feet wide on top, and with such side slopes that the resultant of all pressures would fall well within the central third with 10 feet of water passing over the crest. With the 200-foot dam, the length of which is 1,400 feet, the maximum observed flood, 40,000 second-feet, would have had a depth on its crest of 4.2 feet; and with the 140-foot dam, which is 1,100 feet

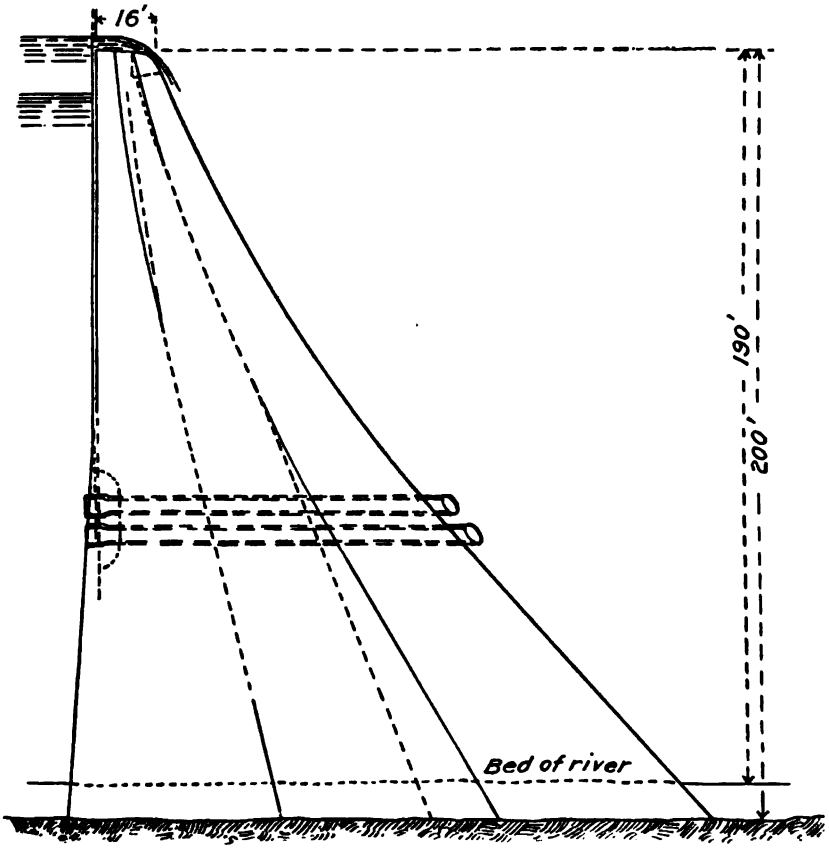


FIG. 2.—Section of proposed Pine Flat weir.

long, this depth would have been 4.8 feet, assuming that all water passed over the crest. Bed rock is at the surface on the sides and bottom of the canyon at the dam site. It is a firm blue slate. The estimate is for the entire structure bedded 10 feet deep in the rock. A trench of greater depth would have to be sunk and filled with concrete at the upper toe. The bed rock should be given most careful study before construction is begun. The estimate includes an apron of concrete extending from 50 to 60 feet below the lower toe of the dam across its entire width, for the protection of the lower toe.

While estimates are given for both a 140-foot and a 200-foot dam, the 140-foot is considered the better for the location.

This reservoir site, although costing nearly double that of Clarks Valley per acre-foot of storage capacity, is of importance in the ultimate development of the lands under Kings River. Being on the main stream it would catch the flood discharge up to its full capacity. It is just above the diversions of all irrigation canals and above the proposed diversion canal line to the Clarks Valley reservoir site, which is not on the river. (See map of drainage basin, Pl. I.) Thus it could be used as a regulator or governor to the river for the conveyance of water to the Clarks Valley reservoir, and, after that had been filled, for the holding of the surplus water. For example, it is obvious that so great a volume as passed in January, 1896 (see discharge diagram, Pl. VII), when on the 18th the discharge increased to 8,500 second-feet and on the 11th to 11,020 second-feet, must be in large part lost in passing the headworks of the diversion canal (capacity 1,250 second-feet) to the Clarks Valley site and the irrigation canals (combined capacity of 4,000 second-feet); but with this large regulator on the main stream all of the water would be saved and gradually discharged into the Clarks Valley canal, leaving the Pine Flat reservoir empty and in readiness for the next flood. The indirect benefit of the Pine Flat reservoir as a governor would be as great as its direct utility as a storage reservoir, and the site should be controlled by the irrigation interests of Kings River.

Discharge of Kings River, showing amounts of water available for storage.[a]

Seasonal year, November to October, inclusive.	Total seasonal discharge Nov. 1 to Oct. 31.	Total seasonal diversion Nov. 1 to Oct. 31.[b]	Diversion Nov. 1 to Feb. 28.[c]	Summer.	Irrigation diversion Mar. 1 to Oct. 31.[d]	Surplus after summer diversion Mar. 1 to Oct. 31.
	Acre-feet.	*Acre-feet.*	*Acre-feet.*		*Acre-feet.*	*Acre-feet.*
1895-96	1,852,425	1,070,900	134,152	1896	936,748	915,676
1896-97	2,088,924	1,198,691	168,846	1897	1,029,845	1,059,079
1897-98	876,079	820,522	164,220	1898	656,302	219,777
1898-99	1,227,217	996,307	102,348	1899	893,959	333,258
1899-1900[e]	1,281,051	1,032,158	214,527	1900	817,631	463,420
Mean	1,465,139	1,023,716	156,819	.....	866,897	598,242

[a] From gagings of the United States Geological Survey at Red Mountain station.
[b] This assumes a diversion from the river of 4,000 second-feet (the full capacity of the irrigation canals) between March 1 and October 31 and 2,000 second-feet between November 1 and February 28, when the water in the river is available.
[c] Total flow of river up to 2,000 second-feet.
[d] Total flow of river up to 4,000 second-feet.
[e] The season of 1900-01 was one of abundant supply.

It is believed that if an ample summer supply is assured midwinter irrigation will be largely if not entirely discontinued.

By reference to the table on page 21, giving a summary of the stream measurements by the California State engineering department and by the United States Geological Survey, it will be seen that during a period of observation of ten years the season of 1897–98 (summer of 1898) had the lowest flow, the season of 1878–79 being next, with a discharge of 397,886 acre-feet more than in the former season. A

twenty-three year rainfall record at Fresno (see table on page 16) shows the year of lowest precipitation to have been 1878–79, when 4.87 inches fell, the next lowest being the season of 1897–98, when 4.95 inches were observed. The official rainfall record at Sacramento (see table on page 16) shows the lowest precipitation during the period over which the record extends (1877–1900) to have been in the season of 1897–98, the amount being 10.50 inches. It will be noted that stream measurements have been made during the years of lowest observed rainfall at Fresno, and that both five-year periods (page 21) were during cycles of low rainfall. In fact not one of these years was a wet year. An old rainfall record kept at Sacramento by Dr. Thomas Logan since 1849 shows dry-year records as follows: 1850–51, 4.71 inches; 1863–64, 7.87 inches; 1870–71, 8.47 inches. The Central Pacific Railway shows a record of 8.95 inches in 1876–77. All of these are below the observed rainfall of 10.50 inches at Sacramento in 1897–98. It is not believed that a standard rain gage was available at Sacramento in the winter of 1850, and the record of 4.71 inches is so much below any other record during the fifty-one years of observation that it may be seriously questioned.

In view of all the facts, the following conclusions seem justifiable:

(1) The observed flow of Kings River for the season of 1897–98 may be assumed to be a very low discharge but not an absolute minimum. For the purpose of this report it may, however, be taken as a minimum.

(2) These minimum years probably will occur about once in ten years.

(3) There will be enough water during November to February, inclusive, in excess of the 4,000 second-feet summer diversions (March to October), to fill the Pine Flat reservoir every year if the dam is built to a height of 140 feet, capacity 78,197 acre-feet.

(4) In nine out of ten years there will be enough water to supply all winter and summer irrigation on the present basis and leave the Pine Flat reservoir full for use after July 1.

(5) The water that would be stored in the Pine Flat reservoir is water that otherwise would be lost.

(6) The Pine Flat reservoir would irrigate the most valuable lands in Fresno and Tulare counties, now dry and unproductive.

(7) The cost of reservoir would be $22.38 per acre-foot stored, and the earning powers of the reservoir many times that amount.

The available water supply is discussed further in connection with the Clarks Valley reservoir site (pages 39 to 42).

CLARKS VALLEY.

After completing the work in the drainage basin of Kings River a reconnaissance of the foothills was made, extending as far as the mouth of San Joaquin River on the northwest and on the southeast to 15 miles from the mouth of Kings River, with a view to finding, if possible, a storage basin to which the flood waters of the river could

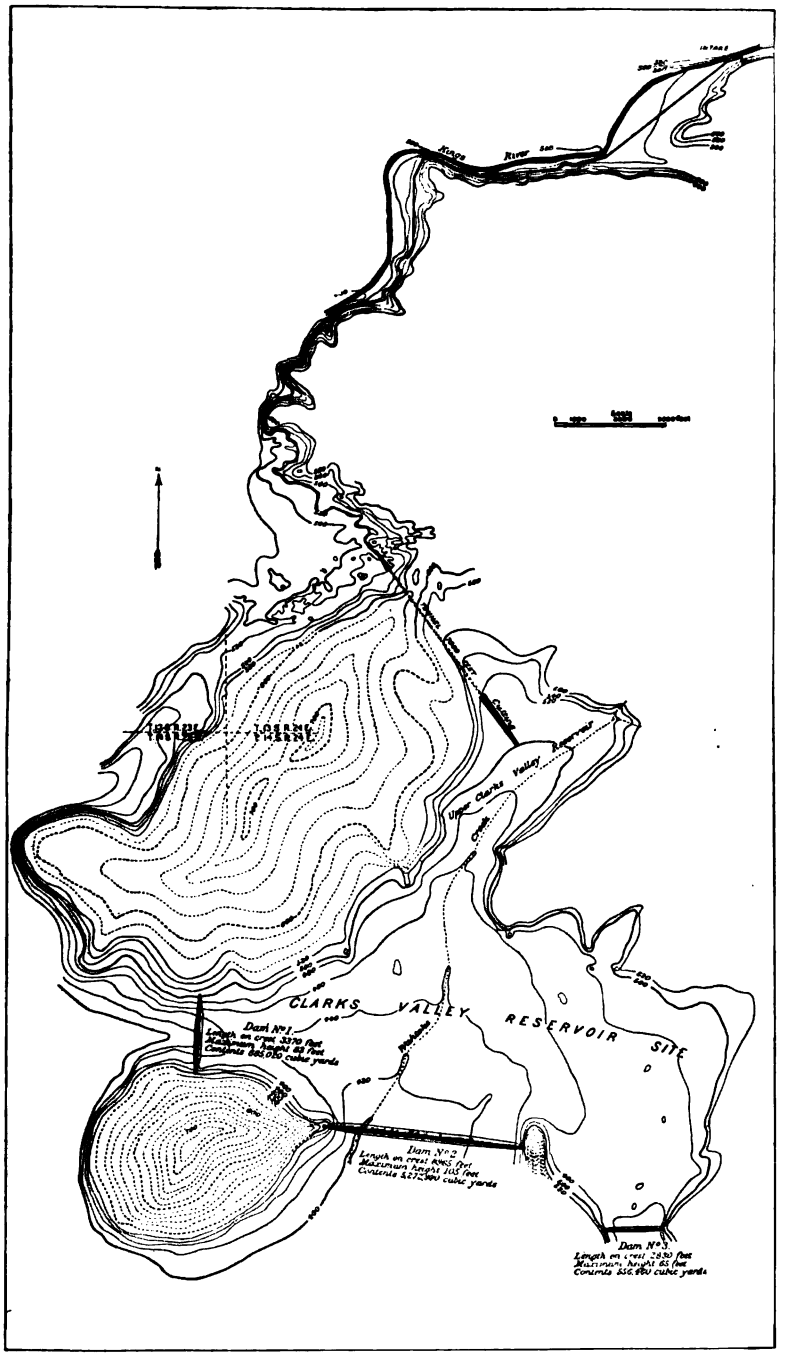
be diverted. The only basin found was Clarks Valley. This reservoir site is in Fresno County, 16 miles east of Sanger. The stage road from Sanger to Millwood runs from west to east through the center of the site. In elevation it commands all of the canals diverting water from Kings River except the Gould canal, and is within 2 or 3 miles of the intake of most of those systems. It is about 1½ miles distant from the main drainage line on Kings River opposite the reservoir and approximately 100 feet higher. It is proposed to fill this reservoir, by means of a diversion canal, with the flood and excess waters of Kings River. The diversion canal would be 53,600 feet in length. The headworks would be above the mouth of Mill Creek and at the Pine Flat dam site.

One rather peculiar feature of Clarks Valley is that three isolated buttes partially inclose a portion of San Joaquin Valley between themselves and the foothills of the main range. To make the reservoir complete the openings between these hills will have to be closed by three separate dams. The arroyo of Wahtoke Creek, which passes through the center of the reservoir site, is about 75 feet wide and 20 feet deep. The maximum height of dam is considered from the bottom of this arroyo, which gives a somewhat exaggerated idea of it. (See Pl. XIII.) The location will permit the construction of a dam 105 feet maximum height, which will impound water to a maximum depth of 100 feet. For the purpose of this report it was decided to give estimates on the cost of building a dam of 105 feet maximum height and also one of 85 feet maximum height, to impound water to maximum depths of 100 feet and 80 feet, respectively. The heights of the two smaller dams will depend upon the height of the larger or central dam, as shown in the tables on pages 35 and 37.

The drainage area of the basin of Wahtoke Creek, in which the Clarks Valley site is located, is 33 square miles. The average elevation of the drainage basin is 1,000 feet. Assuming the average annual rainfall to be 20 inches and the run-off 12 per cent, we have 4,224 acre-feet as the amount of water available for storage from the local drainage basin. The assumed elevation at the base of the dam is 400 feet, which is the elevation used for maps and calculations. For sea level 29 feet should be added. The capacity of the reservoir at different heights of the water is given in the following table. The elevation of the outlet is 420 feet.

Capacity of Clarks Valley reservoir site.

Maximum depth of water.	Area.	Capacity of section.	Total capacity.
Feet.	*Acres.*	*Acre-feet.*	*Acre-feet.*
0	0.0	.....	.....
20	248.3	Below outlet.	.....
40	1,146.0	13,943	13,943
60	2,502.2	37,382	51,325
80	4,325.2	69,174	120,499
100	5,344.5	96,697	217,196



CONTOUR MAP OF CLARKS VALLEY RESERVOIR SITE AND PROPOSED DIVERSION CANAL.

The dams would be of earth, the material in each case being near enough to the dam site to readily be transported by cables or other mechanical devices. A reddish clay containing about 10 per cent of coarse gravel and some sand can be used.

105-FOOT DAM.

The following quantities are for a large dam 105 feet high, 20 feet wide on top, with a slope of 2½ to 1 on the upstream side and 1½ to 1 on the lower side.[a] The maximum depth of water will be 100 feet and the storage capacity 217,196 acre-feet.

Quantities of material for 105-foot dam and the two side structures.

Dam.	Length on crest.	Greatest depth.	Earth.
	Feet.	*Feet.*	*Cu. yds.*
No. 1	3,370	83	885,020
No. 2	3,865	105	5,272,990
No. 3	2,830	65	556,460
Total			6,714,470

At 20 cents per cubic yard the cost of the dams would be $1,342,895.

To fill the reservoir to the 100-foot level (217,196 acre-feet) a conduit with a capacity of 1,250 cubic feet per second would be required. The total length of this conduit, from the headworks on Kings River to the reservoir, would be 53,600 lineal feet, as follows: 7,000 feet of tunnel into reservoir, 3,600 feet of cutting at entrance and discharge of tunnel, and 43,000 feet of canal partly in rock.

Intake tunnel.—The elevation of the bottom of the inlet tunnel at its reservoir end is fixed at 20 feet above the maximum flow line for the larger (105-foot) dam, so as to permit raising the dam in the future. The elevation of the intake at Kings River is estimated at 558.5 feet. The elevation of the Pine Flat dam site is approximately 600 feet. The cross section of the inlet tunnel will be 10½ feet by 12 feet, and the velocity of the water will be 10 feet per second. The tunnel will be in granite. The estimated cost, unlined, is $12 per running foot, or a total of $84,000, exclusive of the tunnel approaches, the cost of which will be as follows:

Cutting at entrance to tunnel:	
13,700 cubic yards of rock at $1	$13,700
27,410 cubic yards of earth at $0.20	5,482
Cutting at discharge end of tunnel:	
10,072 cubic yards of rock at $1	10,072
5,036 cubic yards of earth at $0.20	1,007
Total	30,261

[a] This section is assumed for the purpose of this estimate and is not necessarily final. This important matter should be most carefully considered before construction is begun and determined only after detailed examination of the material available and of the foundations.

Diversion canal.—The canal will have a capacity of 1,250 cubic feet per second and a grade of 1.056 feet to the mile in earth and loose rock and 3.168 feet to the mile in solid rock section. The bottom width will be 17 feet and the cost as follows:

Earth, 362,000 cubic yards at $0.20	$72,400
Loose rock, 401,505 cubic yards at $0.50	200,750
Solid rock, 78,600 cubic yards at $1	78,600
Total	351,750

Sections of the canal in earth and loose rock and in solid rock are shown in Pl. XIV.

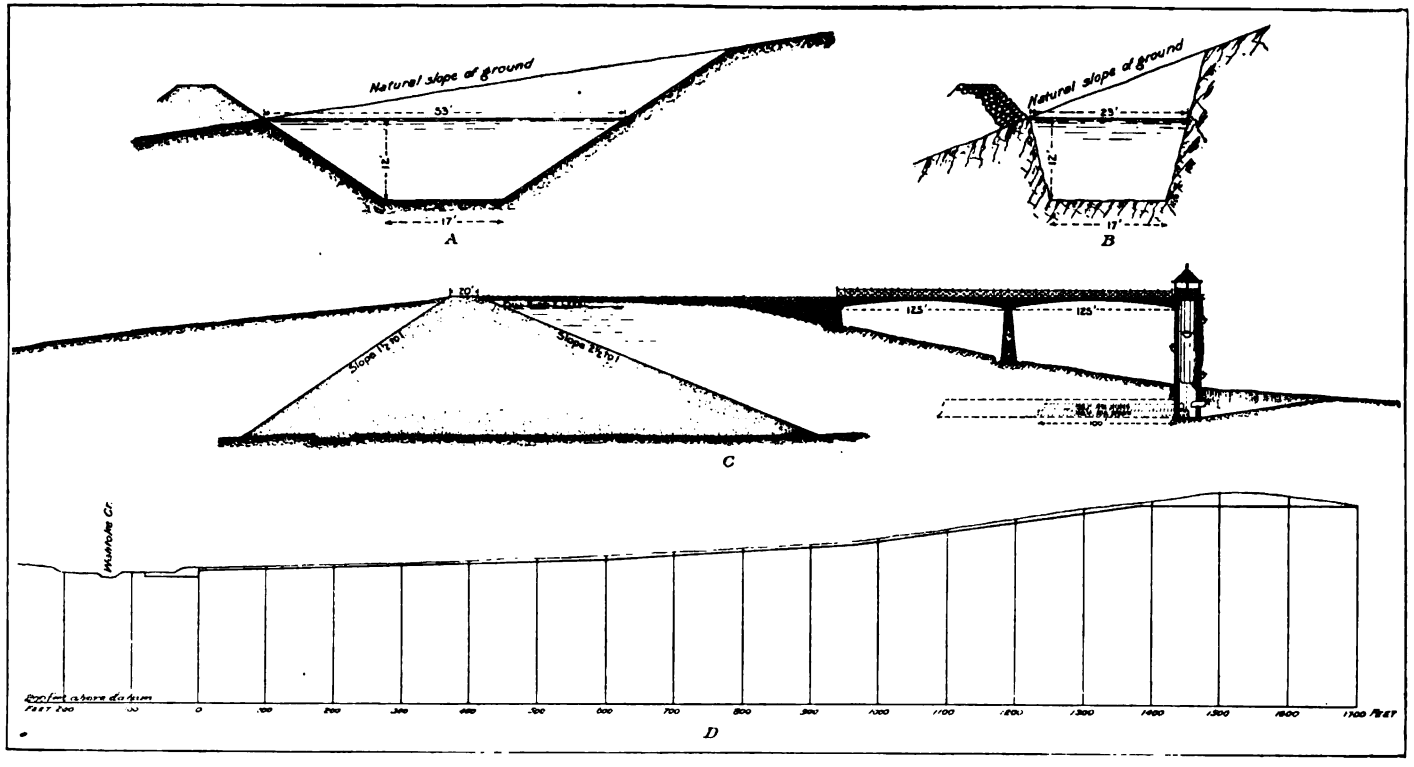
Spillway at dam No. 2.—This spillway will be 100 feet wide, with a capacity of 1,698 cubic feet per second and a depth of water of 3 feet. The cost will be as follows:

25,886 cubic yards of rock at $1	$25,886
16,650 cubic yards of earth at $0.25	4,163
Concrete walls and foundations in earth	24,725
Water cushion at foot of spillway	3,006
Total	57,780

The spillway will have to provide for floods in the local drainage basin (33 square miles) of Wahtoke Creek only. The area of the reservoir at the 100-foot level is 5,344 acres, and if there were no spillway it would require a flood of 2,672 second-feet for one day to raise the water level 1 foot. The top of the dam will be 5 feet above the spillway. The west end of dam No. 2 is shown in plan and section in Pl. XV, *A*, and a longitudinal section of the spillway in Pl. XIV, *D*.

Outlet tunnel, tower, gates, etc.—Pl. XV, *B*, shows a cross section and a longitudinal section of the outlet channel, and Pl. XIV, *C*, combined sections with tower. The cost of the outlet tunnel, tower, gates, etc., is as follows:

Outlet tunnel, 1,100 lineal feet, 10 feet by 12 feet clear section, cement lined, at $12		$13,200
Cutting approach to tower:		
1,381 cubic yards of rock at $1	$1,381	
2,762 cubic yards of earth at $0.25	690	
Cutting at discharge end of tunnel:		
741 cubic yards of rock at $1	741	
1,481 cubic yards of earth at $0.25	370	
		3,182
Concrete valve tower, 12 feet inside diameter and 85 feet high	3,352	
Concrete dam, 100 feet long, connecting tower with tunnel	2,782	
Four pipes through concrete dam, each 48 inches in diameter by 100 feet long, with gates attached, at $1,500	6,000	
Tower valves and appliances, seven at $500	3,500	
House on top of tower	500	
Concrete and iron footbridge to tower, two spans of 125 feet each	5,000	
Concrete and iron footbridge over spillway, 100 feet	2,000	
		23,134
Total		39,516



DETAILS OF PROPOSED RESERVOIR IN CLARKS VALLEY.

A, Section of canal in earth and loose rock; *B*, section of canal in solid rock; *C*, combined sections, showing tower; *D*, longitudinal section of spillway.

Headworks on Kings River.—The estimated cost of diverting dam, sand box, gates, etc., is $25,000.

Summary of cost.—Summarizing, the cost of the works with large dam 105 feet high, storing 217,196 acre-feet, is as follows:

Dams Nos. 1, 2, and 3	$1,342,895
Inlet tunnel, or feed conduit	84,000
Cutting at each end of inlet tunnel	30,261
Canal between intake and tunnel approach	351,750
Spillway at dam No. 2	57,780
Outlet tunnel	13,200
Cutting at each end of outlet tunnel	3,182
Valve tower, gates, etc	23,134
Intake works on Kings River	25,000
Right of way	75,000
	2,006,202
Engineering and contingencies, 10 per cent	200,620
Total	2,206,822

The cost per acre-foot of water stored is $10.15.

Annual cost per acre-foot of water delivered.—Figuring the interest at 6 per cent of the cost of the works ($2,206,822), the taxes at eight-tenths of 1 per cent of the cost, and maintenance for the reservoir and diversion canal at $10,000 per annum, we have an annual charge against the plant of $160,064. We have found that the evaporation would amount to 3½ per cent of the entire storage capacity of the larger reservoir; but if we take the evaporation at 5 per cent and the seepage in the canal at 15 per cent we have 173,757 acre-feet available for delivery. This divided into the annual charge of $160,064 gives an annual cost per acre-foot of water delivered from the reservoir to the lands of $0.92.

85-FOOT DAM.

The following quantities are for a large dam 85 feet high, 20 feet wide on top, with a slope of 2½ to 1 on the upstream side and a slope of 1½ to 1 on the downstream side. The maximum depth of water will be 80 feet and the storage capacity 120,499 acre-feet.

Quantities of material for 85-foot dam and the two side structures.

Dam.	Length on crest.	Greatest depth.	Earth.
	Feet.	*Feet.*	*Cu. yds.*
No. 1	3,100	63	504,189
No. 2	8,640	85	3,085,171
No. 3	2,585	43	248,468
Total			3,837,828

At 20 cents per cubic yard the cost of the dams would be $767,566.

To fill the reservoir to the 80-foot level (120,499 acre-feet) a conduit with a capacity of at least 525 cubic feet per second would be required. The total length of the conduit from the headworks on Kings River to the reservoir would be 53,600 feet, divided the same as for the 105-foot dam, i. e., 7,000 feet of tunnel, 3,600 feet of cutting at entrance and exit of tunnel, and 43,000 feet of diversion canal.

Intake tunnel.—The feed tunnel will be of the same dimensions and grade and in the same location as for the 105-foot dam—7,000 lineal feet in solid rock, unlined, at $12 per lineal foot, $84,000, plus the cost of cutting at the entrances, $24,790. The elevation of the lower end of the inlet tunnel is fixed at 520 feet, the same as for the larger reservoir, so as to permit increasing the height of the dam in the future, if desired. The elevation of the intake is taken at 558.5 feet.

Diversion canal.—The canal will have a capacity of 525 cubic feet per second and a grade of 1.584 feet to the mile in earth and loose rock and 4.224 feet to the mile in solid rock section. The bottom width will be 10 feet and the cost as follows:

151,330 cubic yards of earth at $0.20	$30,266
30,840 cubic yards of rock at $1	30,840
166,140 cubic yards of loose rock at $0.50	83,070
Total	144,176

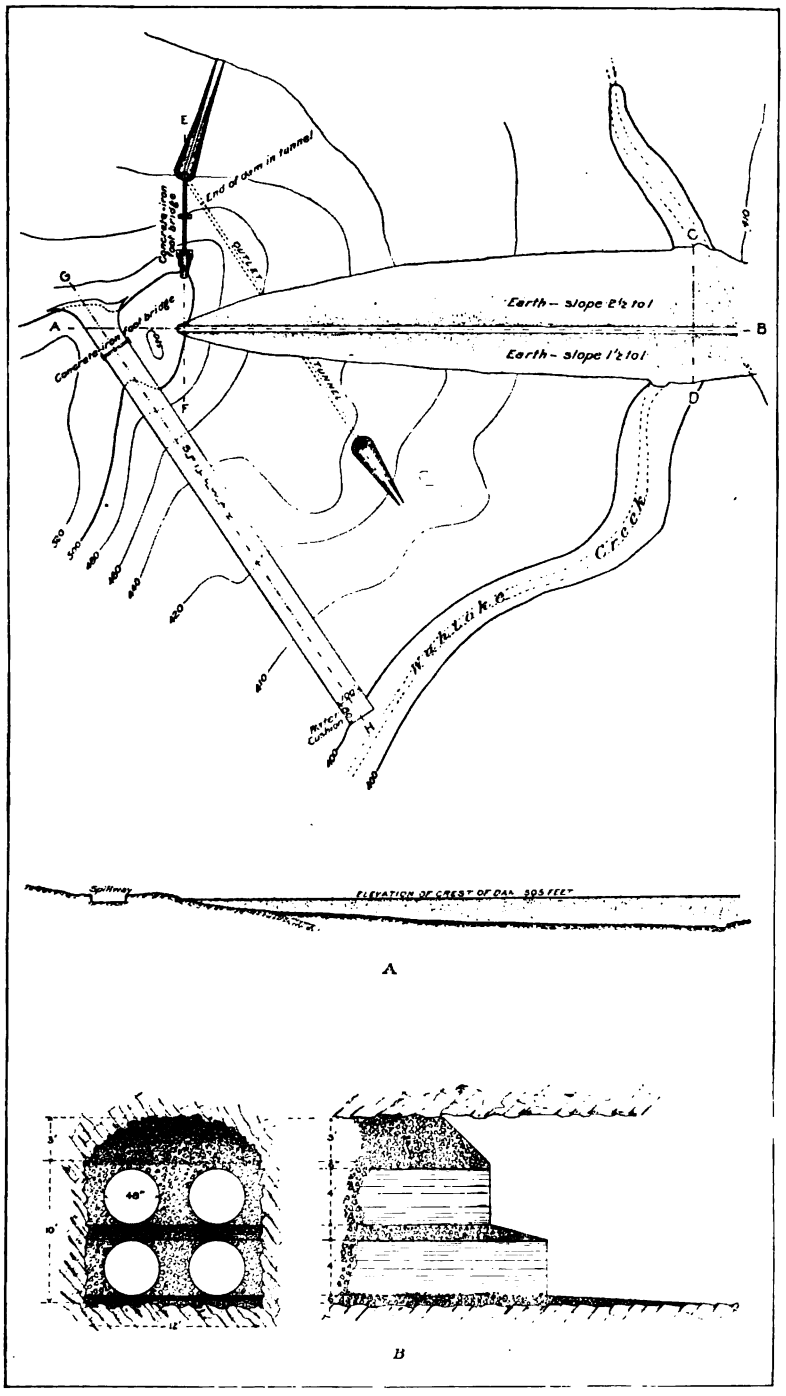
Spillway at dam No. 2.—The spillway will be 100 feet wide, with a capacity of 940 cubic feet per second and a depth of water of 2 feet. The cost will be as follows:

13,625 cubic yards of earth at $0.25	$3,406
27,251 cubic yards of rock at $1	27,251
Foundation in earth, 3,000 cubic yards at $0.50	1,500
Concrete in walls and bottom, 3,000 cubic yards at $6	18,000
Total	50,157

Outlet tunnel, tower, gates, etc.—The cost of the outlet tunnel and of cutting approach to tower and at discharge end of tunnel would be practically the same as for the 105-foot dam. The estimate of cost of tower, gates, etc., is as follows:

Concrete valve tower, 12 feet inside diameter and 85 feet high	$3,352
Concrete dam 100 feet long, connecting tower with tunnel	2,782
Four pipes through concrete dam, each 48 inches diameter by 100 feet long, with gates attached, at $1,500	6,000
Tower valves and appliances, seven at $500	3,500
House on top of tower	500
Concrete and iron footbridge to tower, two spans of 125 feet each	5,000
Concrete and iron footbridge over spillway, 100 feet	2,000
Total	23,134

Headworks on Kings River.—The estimated cost of diverting dam, sand box, gates, etc., is the same as for the 105-foot dam, viz, $25,000.



DETAILS OF PROPOSED RESERVOIR IN CLARKS VALLEY.

A, Plan and section of west end of dam No. 2; *B*, cross section and longitudinal section of outlet tunnel.

Summary of cost.—Summarizing, the cost of the works with large dam 85 feet high, storing 120,499 acre-feet, is as follows:

Dams Nos. 1, 2, and 3	$767,566
Feed tunnel	84,000
Cutting at each end of inlet tunnel	24,790
Diversion canal between intake and tunnel approach	144,176
Spillway at dam No. 2	50,157
Outlet tunnel	13,200
Cutting approaches at each end of outlet tunnel	3,000
Valve tower, gates, etc	23,134
Headworks on Kings River	25,000
Right of way	75,000
	1,210,023
Engineering and contingencies, 10 per cent	121,002
Total	1,331,025

The cost per acre-foot of water stored is $11.05.

Annual cost per acre-foot of water delivered.—Figuring the interest at 6 per cent of the cost of the works ($1,331,025), the taxes at eight-tenths of 1 per cent of the cost, and maintenance for the reservoir and diversion canal at $10,000 per annnm, we have an annual charge against the plant of $100,510. We have found that the evaporation would amount to 4.7 per cent of the entire storage capacity of the reservoir, but if we take the evaporation and seepage at 20 per cent, as for the 105-foot dam, it would leave 96,399 acre-feet available for delivery. This divided into the annual charge of $100,510 gives an annual cost per acre-foot of water delivered from the reservoir of $1.04.

WATER SUPPLY.

Assuming the annual rainfall to be 20 inches over the 33 square miles of drainage area of Wahtoke Creek, and the run-off to be 12 per cent, we have 4,224 acre-feet. The storage capacity of the 105-foot dam is 217,196 acre-feet. This, less the 4,224 acre-feet from rainfall in the local drainage basin, gives 212,972 acre-feet of water to be brought by diversion conduit from Kings River. In order to determine whether a canal with a capacity of 1,250 second-feet would fill the reservoir, the following assumptions have been made:

(1) That all of the water in Kings River up to the capacity of the canal (1,250 second-feet) can be diverted during the months of November, December, January, and February.

(2) That the combined capacity of the canals diverting water from the river during the remaining months is 4,000 second-feet, and the surplus above that amount is available, to 5,250 second-feet, for storage.

The following statement, based on the daily discharge of the river at the Red Mountain gaging station of the United States Geological Survey, which is practically at the proposed point of diversion, shows the amounts of water which could have been diverted with a dam 105

feet high and a canal of 1,250 second-feet capacity, under the foregoing conditions.

Available water supply, in acre-feet, of Clarks Valley reservoir site with 105-foot dam.

Month.	Season 1895-96.	Season 1896-97.	Season 1897-98.	Season 1898-99.	Season 1899-1900.*
November	20,838	31,989	36,935	13,741	37,877
December	20,067	30,591	45,438	18,929	48,237
January	47,742	26,841	31,312	31,395	66,485
February	47,398	67,855	39,105	36,575	41,491
March	3,663	808	.....	5,444	.....
April	3,564	44,368	25,404	39,497	.....
May	30,393	76,725	12,474	8,890	46,186
June	74,072	38,662	.....	47,144	41,715
July	26,758	79	.....	.....	.....
Total	274,495	317,918	190,668	201,595	281,991

* The season of 1900-01 was one of abundant supply.

Taking the season of least available flow (1897–98) we have 190,668 acre-feet. If we add to this the amount of water available from the local drainage basin (4,224 acre-feet) we have a total of 194,892. This is 22,304 acre-feet, or 9½ per cent, less than the maximum capacity of the reservoir for a year of extreme drought, which is not likely to occur but once in ten years. For the season of 1898–99 the amounts would be 201,595 acre-feet from the river and 4,224 acre-feet of rainfall stored, giving a total of 205,819 acre-feet, or 11,377 acre-feet less than the maximum storage capacity. That year also was one of drought. For the remaining three seasons of observation the flow is more than sufficient. The rainfall records at Fresno indicate the last five years to have been the driest observed since 1877, and it is believed that they may be accepted as a minimum.

In connection with the foregoing figures there is an important point to be considered, viz: If the people who now are using the flow of the river in March and October to flood their lands could be assured of a sufficient quantity of water later in the season, part of the flow of the river for those months could be diverted to the reservoir, and thus the reservoir be filled to its maximum capacity each year. The following table shows the quantities of water that could have been diverted from Kings River by a canal of maximum capacity of 525 second-feet and an 85-foot dam, under conditions similar to those prevailing for the 105-foot dam:

Available water supply, in acre-feet, of Clarks Valley reservoir site with 85-foot dam.

Month.	Season 1895-96.	Season 1896-97.	Season 1897-98.	Season 1898-99.	Season 1899-1900.
November	19,394	28,403	28,086	13,741	28,849
December	20,067	30,444	32,224	17,494	30,829
January	28,185	26,552	30,650	28,225	32,224
February	30,145	29,106	28,819	28,453	29,106
March	2,079	808	.....	2,673	.....
April	3,118	20,638	12,929	18,572	.....
May	18,711	32,224	6,049	7,286	20,344
June	31,185	16,632	.....	22,879	21,236
July	12,432	79	.....	.....	.....
Total	165,316	184,886	138,757	139,323	162,588

Using the season of minimum observed flow (1897–98) we have 138,757 acre-feet available flow from the river, which with the 4,224 acre-feet from the local basin gives a total of 142,981 acre-feet, or 22,482 acre-feet more than the maximum storage capacity of the reservoir.

If the Pine Flat and the Clarks Valley dams are both built the following tables will show the available supply. These tables (determined by planimeter from the diagrams of stream flow) are based (1) upon a diversion by the irrigation canals of water to their full capacity, viz, 4,000 second-feet, from March 1 to October 31, and (2) upon the fact that with the regulating reservoir at Pine Flat the Clarks Valley reservoir could have been completely filled, to either the 100-foot or the 80-foot level, each year.

The entire capacity of the Clarks Valley reservoir less the supply from the local drainage basin (4,224 acre-feet) is therefore also deducted from the seasonal flow of the river each year. All of the water remaining in the river is considered available for storage at Pine Flat. It is reasonably certain that both reservoirs would have been completely filled during the five-year period of observation by the State engineering department, i. e., 1878 to 1883. It must be remembered that the ten years for which we have records were below the average in rainfall and run-off. The year 1897–98 may be taken as the minimum of a ten-year period of low rainfall. The season of 1900–1901 is now (June 1, 1901) far enough advanced to show that the supply for this year would have been more than ample to fill both reservoirs. The table shows that with the larger dam at Clarks Valley (the 105-foot) there would have been one year out of the eleven that the Pine Flat reservoir could not have been filled.

Available water supply, in acre-feet, for 140-foot dam at Pine Flat reservoir site with 105-foot dam at Clarks Valley reservoir site.

Season Nov. 1 to Oct. 31.	Total discharge of river.	Clarks Valley diversion.	Irrigation diversion Mar. 1 to Oct. 31.	Available for Pine Flat reservoir (capacity, 78,197 acre-feet).
1895–96	1,852,425	212,972	936,749	703,704
1896–97	2,088,924	212,972	1,029,845	846,107
1897–98	876,079	212,972	656,302	6,805
1898–99	1,227,217	212,972	893,959	120,286
1899–1900	1,281,051	212,972	817,631	250,448
Five-year mean	1,465,139	212,972	866,897	385,470

The foregoing table shows the possibility of having used 79 per cent of the average flow of Kings River during the last five years.

Available water supply, in acre-feet, for 140-foot dam at Pine Flat reservoir site with 85-foot dam at Clarks Valley reservoir site.

Season Nov. 1 to Oct. 31.	Total discharge of river.	Clarks Valley diversion.	Irrigation diversion Mar. 1 to Oct. 31.	Available for Pine Flat reservoir (capacity, 78,197 acre-feet).
1895-96	1,852,425	116,275	936,749	800,401
1896-97	2,088,924	116,275	1,020,845	942,804
1897-98	876,079	116,275	656,302	103,502
1898-99	1,227,217	116,275	898,959	216,983
1899-1900	1,281,051	116,275	817,631	347,145
Five-year mean	1,465,139	116,275	866,897	482,167

The foregoing table shows that both reservoirs could have been filled every year during the period given.

Normally the reservoir at Clarks Valley, as previously stated, would be full at the end of June and empty at the end of September. The period during which evaporation will have to be considered is the months of July, August, and September. The evaporation observations given herein show that the mean evaporation during those months is 1.89 feet each year. The total storage capacity of the reservoir at the 100-foot level is 217,196 acre-feet; the area at the 100-foot level is 5,344 acres and at the 80-foot level 4,325 acres. For the purpose of this estimate the average area for the larger reservoir exposed to evaporation may be considered as 4,000 acres, losing in depth 1.89 feet each year, or 7,560 acre-feet, which is 3½ per cent of the total storage capacity of the reservoir. With the smaller dam the evaporation would amount to 4.7 per cent, or 5,670 acre-feet.

SPILLWAY.

The Clarks Valley reservoir will be almost entirely free from attacks of floods, as the local drainage basin contains only 33 square miles, and its annual discharge will probably be equal to a depth of about 1 foot in the reservoir at the 100-foot level. The diversion canal, having a capacity of 1,250 second-feet, or 2,500 acre-feet, per day, would require two days' flow to raise the water in the reservoir 1 foot in height when it stands at the 100-foot level. The capacity of the outlet from the reservoir will be 1,280 cubic feet per second (greater than that of the intake), with 10 feet head on the valves. This will be in addition to the capacity of the spillway.

The months during which the maximum amount of water is available for storage from Kings River are May and June. This is after the expiration of the rainy season, and it will be the discharge of the diversion canal during these two months that will finally fill the reservoir each year. Since 1877 the greatest rainfall that has occurred

in May was 1.97 inches, in 1900. On this basis the water that fell in the local drainage basin of Wahtoke Creek would amount to 3,380 acre-feet. The area of the reservoir at the 100-foot level is 5,344 acres.

Since 1877 there have been only three occasions when rain has fallen at Fresno during the month of June, the greatest precipitation for that month being 1.29 inches, in 1884. It is therefore reasonable to assume that during the time the reservoir is full the local drainage basin can never deliver a volume of water sufficient to raise the level of a full reservoir more than 1 foot, even if the discharge gate and the spillway are both closed. It is proposed to make the elevation of the spillway 7 feet below the top of the dam and to maintain the water in the reservoir at that height during the entire rainy season. After the expiration of the rainy season—say the first of June—it would be safe to place flashboards in the spillway, so as to store 2 feet more of water. This would bring the water to the maximum depth of 100 feet, would add about 10,000 acre-feet to the storage capacity, and would still leave the top of the reservoir 5 feet above the level of the water. If it should be considered desirable to increase the interval between the water level and the top of the dam it could most economically be done by increasing the height of the dam 2 or 3 feet on slopes of 1½ to 1 on each side. It will be remembered that there probably would not be more than two weeks intervening between the complete filling of the reservoir and the beginning of the discharge from it.

A longitudinal section of the spillway proposed is shown in Pl. XIV, *D*.

RESERVOIR SURVEYS.

On June 19 the party reported at Sanger, Fresno County, on the Southern Pacific Railroad, where camp equipment was received. A pack train of 5 mules and 4 saddle horses was purchased in the neighborhood, at an average cost of $40 per animal. The party, which was in charge of Mr. H. E. Green, consisted of a topographer, two rodmen, a packer, and a cook. After July 12 one rodman was dispensed with, reducing the party to four.

On June 22 the party left Sanger, at an elevation of 370 feet, and started for Millwood. Following the county road and crossing to the south of Kings River near Centerville, the foothills were reached about 16 miles from Sanger, the road traversing the lower Clarks Valley reservoir site. From Clarks Valley to Millwood the road ascends 4,710 feet in a distance of 30 miles, the elevation of Millwood being 5,210 feet, aneroid measurement. From Millwood the party went into camp at Long Meadow, where the first survey work was done on the Long Meadow reservoir site.

LONG MEADOW.

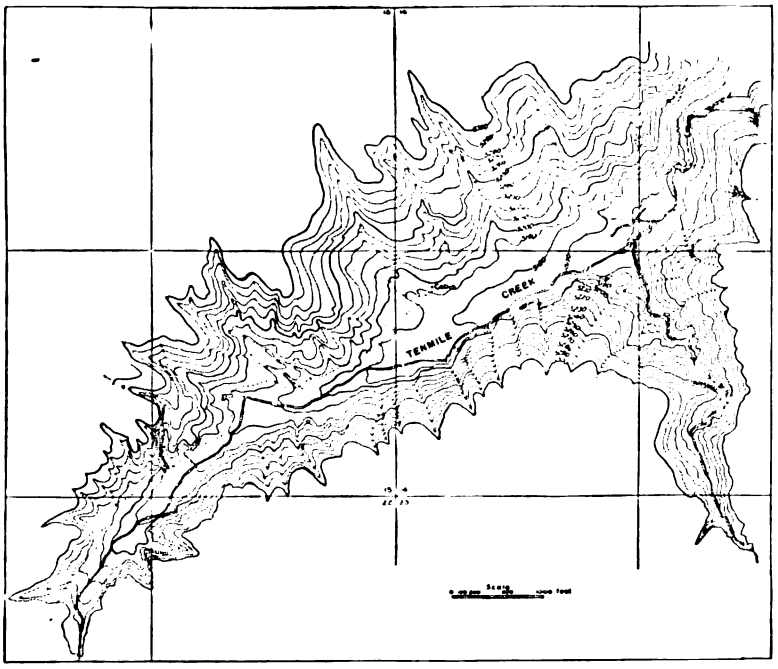
Long Meadow can be reached in 11 miles from Millwood by taking the Sanger Lumber Company's wagon road to their sawmill, a distance of 6 miles, and then following the trail for 5 miles, crossing the divide at an elevation of 6,770 feet; or it can be reached without surmounting such an elevation by keeping the wagon road via the sawmill to Converse Meadow, 12 miles distant and at an elevation of 5,900 feet, and following the trail for 2 miles across the low divide separating Converse Meadow from Long Meadow.

Long Meadow, which is at an elevation of 5,200 feet, is on Tenmile Creek, about 4 miles above its junction with Kings River, which junction is less than a quarter of a mile west of the junction of the Middle and South forks of the river. The reservoir and dam sites are in secs. 14, 15, 22, and 23, T. 13 S., R. 28 E., Mount Diablo base and meridian. The land is owned by the Sanger Lumber Company and is well timbered with pine. The dam site is in the northeast quarter of sec. 14, T. 13 S., R. 28 E. The average elevation of the watershed of the meadow or valley is 7,000 feet above sea level, and the supply of water will be largely from melting snow in the spring. Contour maps of the reservoir and dam sites are shown in Pl. XVI.

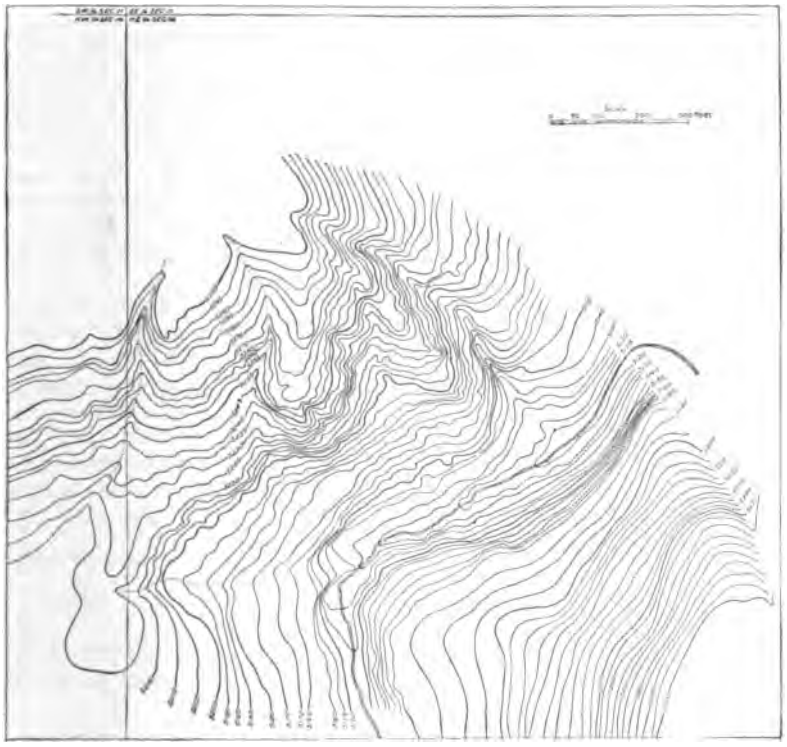
The drainage area tributary to Long Meadow is estimated at 25 square miles. The estimated mean rainfall is 45.3 inches, making the run-off per square mile 900 acre-feet, or $900 \times 25 = 22,500$ acre-feet per year. If we assume a rainfall of 40 inches and a run-off of 50 per cent the average yield would be 26,560 acre-feet per year; or if we assume 2 second-feet run-off per square mile we have 50 second-feet, or 100 acre-feet, per day, which is equal to 36,500 acre-feet per year. The capacity of the reservoir with a dam 170 feet high is 25,334 acre-feet.

Owing to the heavy grade to be surmounted in hauling material from the Southern Pacific Railroad at Sanger via Millwood, which is the shortest approach, a loose rock-fill dam with plank face is considered the most economical. Freight from Sanger to Millwood (45 miles) costs $9 per ton of 2,000 pounds, or 45 cents per hundred pounds. From Millwood freight would go, by the mill road already mentioned, 12 miles to Converse Meadow, elevation 5,900 feet. From there a road would have to be graded over the low divide separating Converse Meadow from Long Meadow. This can be done, with easy gradients, at an estimated length of 4 miles. The proposed method of building the dam is by the use of two Lidgerwood cables, one on the axis of the dam, with traveling towers, and the other crossing the dam, working two quarries, one above and one below the dam site.

The bed rock at the proposed dam site is granite, solid and bare in the creek bed but seamy on the north side of the canyon. It is in



A. CONTOUR MAP OF LONG MEADOW RESERVOIR SITE.



B. CONTOUR MAP OF LONG MEADOW DAM SITE.

strata from 5 to 10 feet thick, with a dip to the south of about 30 degrees. The south side of the canyon will require stripping, probably 8 or 10 feet. It was impossible to carry tools to determine the depth to bed rock, and the estimate of the amount of stripping required is obtained from surface indications. A view of the dam site on the north side of the creek is shown in Pl. XVII, *A*.

Data regarding Long Meadow dam.

Elevation at base of dam	feet	5,130
Elevation of floor of wasteway	do	5,290
Elevation of crest of dam	do	5,300
Elevation of outlet	do	5,150
Height of dam	do	170
Drainage area	square miles	25
Run-off, estimated	acre-feet	22,500
Capacity of reservoir below wasteway	do	25,334
Capacity of reservoir at crest level	do	30,033

Following is the preliminary estimate of cost:

Estimate of cost of loose rock-fill dam at Long Meadow.

Loose rock, 673,000 cubic yards at $0.75	$504,750
Plank face, area 144,800 square feet:	
Two layers of 3-inch plank on lower half of face, 324,000 feet, B. M., at $30	9,720
Two layers of 2-inch plank on upper half of face, 360,000 feet, B. M., at $30	10,800
Sills, 12 inches by 12 inches, spaced 4 feet between centers, equal to a layer of 3-inch timber over entire surface, 432,000 feet, B. M., at $30	12,960
Labor on plank face	6,000
Wasteway, 50-foot bottom width, slopes ¼ to 1, 6 feet depth of water, capacity 2,400 second-feet, length 400 feet, lined with cement:	
Excavation, 15,000 cubic yards of rock at $1	15,000
Cement lining, 3,000 square yards (200 barrels of cement at $8, $1,600; labor, 3,000 square yards at $0.10, $300)	1,900
Outlet tunnel in solid rock, cement lined, 4 feet by 6 feet, arched top and bottom, 500 lineal feet at $10	5,000
Tower, including house and bridge, valves, gates, etc	8,000
Machinery and cable (75-horsepower engine, 2½-inch cable, two traveling towers to handle 10 tons)	26,000
Road from Converse Meadow to Long Meadow (4 miles) and to cable towers and around works (2 miles), 6 miles at $3,000	18,000
Clearing reservoir, 500 acres at $5	2,500
	620,630
Engineering and contingencies, 15 per cent	93,085
Total	713,715

The cost per acre-foot of water stored is $28. Plan, elevation, and maximum cross section of the proposed dam are shown in Pl. XVIII.

The cost of a concrete dam at this site would be much greater than that of a rock-fill dam. The estimate is as follows:

Estimate of cost of concrete dam at Long Meadow.

171,000 cubic yards of masonry at $10	$1,710,000
Wasteway, 50 feet by 10 feet	16,900
Outlet tunnel, 4 feet by 6 feet	5,000
Tower, etc.	8,000
Machinery and cable	26,000
Roads	18,000
Clearing reservoir	2,500
	1,786,400
Engineering and contingencies	100,000
Total	1,886,400

With a concrete dam the cost per acre-foot of water stored is $74, against $28 with a loose rock-fill dam.

EAST LAKE.

From Long Meadow the party moved to East Lake, where the next survey work was done in July. This lake is about 2 miles up the South Fork of Bubbs Creek, which is about 5 miles above the junction of Bubbs Creek with the South Fork of Kings River. The best way to reach the lake is by way of Millwood and Long Meadow, though it can be reached by a shorter route by packing from Independence, Inyo County, by way of Kearsarge Pass.

Starting with Long Meadow as a base (elevation 5,200 feet) the trail goes first to Bearskin Meadow, 5 miles distant and at an elevation of 6,000 feet; then to Horse Corral Meadow, 20 miles distant and at an elevation of 7,820 feet; then to Summit Meadow (overlooking Kings River Canyon), 23 miles distant and at an elevation of 8,150 feet; then to Kings River Canyon, 28 miles distant and at an elevation of 5,000 feet, a descent of more than 3,000 feet in 5 miles. About a mile upstream from the foot of this trail and approximately 12 miles above the junction with the Middle Fork of Kings River, is the log building known as the hotel and a sheep bridge across Kings River. The trail then leads up the South Fork of Kings River to Bubbs Creek, 37 miles distant and at an elevation of 5,370 feet, where the river makes a sharp bend to the north; then up Bubbs Creek to its south fork, 49 miles distant and at an elevation of 8,120 feet; up the South Fork of Bubbs Creek to East Lake, 52 miles from Long Meadow and 63 miles from Millwood, at an elevation of 9,350 feet. From where the trail enters Bubbs Creek it is very steep and rocky, and the 3 miles of it along the south fork of that creek would require a great deal of work to make it passable as a freight trail.

At East Lake the country in all directions is rugged and bare (see Pl. XVII, *B*), being near the limit of the timber line. Only a thin

A. LONG MEADOW DAM SITE.

B. EAST LAKE RESERVOIR SITE.

scattering of tamaracks is to be seen. At the time of the survey (July) considerable snow was still lying on the northern slopes and was feeding the South Fork of Bubbs Creek and its numerous lakes, which make this locality very picturesque.

About 2½ miles above East Lake is Reflection Lake (see Pl. XXI, *A*), which has a water surface of about 30 acres. It is a deep body of water between high, precipitous walls, and is at an elevation of 10,000 feet. Above Reflection Lake, at an elevation of 11,000 feet, are numerous small lakes of from 1 to 3 acres area, all perfectly calm, and reflecting the surroundings as in mirrors. Monuments were found at East Lake which showed that the California State engineering department had made a survey there. A topographic survey was made, under the direction of Mr. Green, with the following results:

East Lake is formed by an immense slide or moraine from Ouzel Creek Canyon on the west, which has dammed the South Fork of Bubbs Creek at that point. The creek formed a lake behind this moraine until it overflowed and washed out the channel where the dam would be located, but the bed of the channel is probably 50 or 60 feet above the old channel bottom, and the mass beneath and to the west is formed of huge blocks of granite embedded in granite débris. That it is not water-tight is proved by the fact that several small streams, caused by melting snow on the solid rock cliffs above the moraine, disappear at the contact of the moraine and appear as springs on the slope immediately above the lake.

There was a stream of water, estimated at 10 second-feet, flowing out of East Lake at the end of July, 1900. A weir dam which would raise the water 70 feet above the lake level would bring enough pressure to bear on the moraine to cause considerable leakage, but it could not wash out, there being too much rock in it, and there is the possibility that it might silt tight.

The area of the watershed tributary to East Lake is estimated at 12 square miles; the average elevation is 11,000 feet. The capacity of a reservoir raised 70 feet above the lake level, which was 9,350 feet at the time of the survey in July, would be 4,154 acre-feet. The lake itself could be utilized to some extent by deepening its mouth so as to permit of an outlet tunnel or pipe being placed low enough to draw off 30 or 40 feet of the water. This would add perhaps 400 acre-feet to the capacity of the reservoir. In like manner Reflection Lake could be utilized, and would yield probably 700 acre-feet additional, making a total of 5,250 acre-feet. No estimate has been made of the cost of a dam, because of the remoteness and inaccessibility of the locality, the cost of transporting material rendering such a project expensive to a degree out of all proportion to the limited capacity of the reservoir. There is no timber available with which to face the dam, and cement would cost from $15 to $20 a barrel delivered. A contour map of the East Lake reservoir site is shown in Pl. XIX.

While the camp was at East Lake a visit was made to Bull Frog Lake, on the north side of Bubbs Creek, about 4 miles east of the south fork of that creek and close to the summit of Kearsarge Pass. On examination no dam site was found and the area of the lake was ascertained to be so small as not to warrant any topographic work. The elevation of the lake is 10,600 feet; the elevation of Kearsarge Pass, 3 miles east of the lake, is 12,000 feet. The drainage area of the lake is about 5 square miles.

GRANITE BASIN.

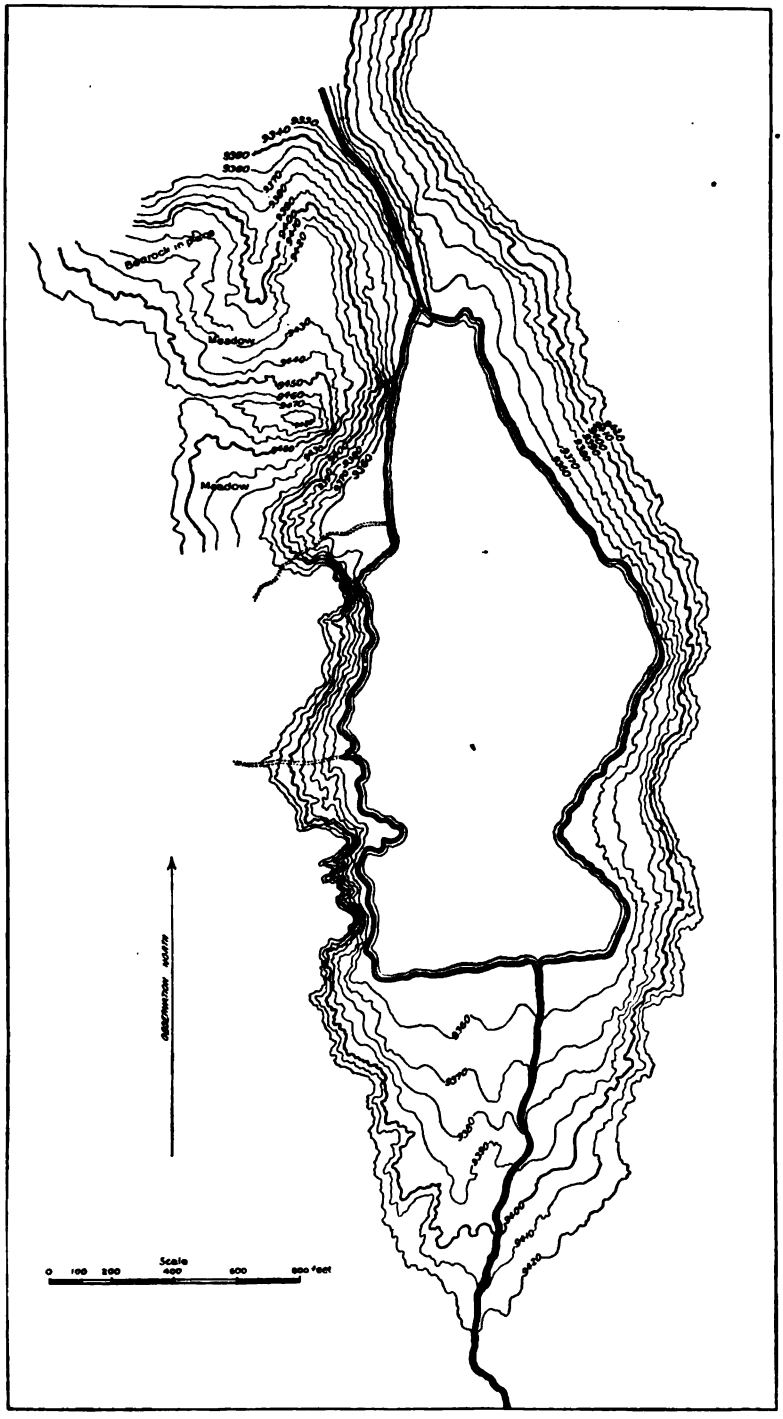
Granite Basin was the next place examined. It is on Granite Creek, at the summit of the divide between Kings River Canyon on the South Fork and the Middle Fork of Kings River. It is reached by trail from Kings River Canyon. Starting at Kanawyer's cabin, elevation 5,200 feet, the trail ascends the steep spur on the west side of Copper Creek, follows Copper Creek for about 7 miles, and crosses the divide at an elevation of 10,300 feet into Granite Creek on the west, 10 miles from Kings River Canyon and at an elevation of 10,000 feet. A contour map of the reservoir site is shown in Pl. XX and a view of the site in Pl. XXI, *B*.

There are two outlets, divided by a butte. The outlet to the northwest would require a dam 750 feet long at the crest and 140 feet high; the outlet to the southeast of the butte would require a dam 900 feet long on the crest and 130 feet high to raise water to the plane of the 10,000-foot contour. A view of one of the outlets is shown in Pl. XXII, *A*. The area within the 10,000-foot contour is 144 acres and the capacity of the reservoir 10,350 acre-feet.

The drainage area tributary to Granite Basin does not exceed 6 square miles and averages 10,800 feet in elevation. There is a sparse growth of tamarack scattered over the basin, the whole of which, however, is practically bare and barren. The bed rock is granite. The capacity of the reservoir compared with the cost of the two large dams necessary to create it and the difficulty of access render the project impracticable.

ELECTRIC-POWER DEVELOPMENT.

In a study of the various irrigation possibilities of Kings River it was deemed advisable to investigate the water power obtainable for the purpose of generating electric energy for transmission to local pumping plants in the valley. This requires an investigation of three distinct phases of the problem: (1) The available power; (2) the available ground-water supply for pumping at or near the irrigated lands; and (3) the generation and transmission of electric power and the installation of pumping plants. The subject will be treated in that order. Mr. H. E. Green was detailed to investigate the water power, Mr. Louis Mesmer the water supply for pumping, and Mr. Lewis A. Hicks the power transmission and pumping plants.



CONTOUR MAP OF EAST LAKE RESERVOIR SITE.

CONTOUR MAP OF GRANITE BASIN RESERVOIR SITE.

POWER POSSIBILITIES.

From Granite Basin the trail passes over a nude and rugged granite country until it drops suddenly into the beautiful Middle Fork Canyon (see Pl. XXII, *B*), at Simpson Meadows, 10 miles from Granite Basin and at an elevation of 6,000 feet. Tehipiti Valley is about 15 miles down the canyon from Simpson Meadows, but the canyon is practically impassable, so the party went by way of Collins Meadow.

Leaving the Middle Fork, elevation 6,000 feet, the trail ascends the West Branch of Goddard Creek and in a distance of 4 miles climbs nearly 5,000 feet up a hard, rocky mountain, with only one bench on which to rest animals and adjust packs. From the top of the ridge, elevation 10,600 feet, a magnificent view is obtained of the country to the south and east across the South Fork of Kings River and Bubbs Creek to the watershed between Kings and Kern rivers. The trail then follows easy country to Collins Meadow, 30 miles from Simpson Meadows, elevation 7,600 feet. Coming from Fresno by way of Ockenden this point is the natural entrance to Tehipiti Valley. From Ockenden there is a wagon road for 15 miles, to Russel's camp, southeast of that place. From Russel's camp the trail follows undulating and pine-covered country presenting easy grades for a continuation of the wagon road toward the North Fork of Kings River. The trail reaches the North Fork at Cliff camp, about 15 miles from Russel's camp and about 3 miles below the Dusy Meadows dam site. The trail to Dusy Meadows branches off about 3 miles before reaching the North Fork.

There is a good bridge site at the North Fork crossing, where the stream is confined between perpendicular walls of granite about 70 feet apart. (See Pl. X.) From the North Fork crossing the trail continues over rolling ground covered with pine and traverses many open glades which have good feed in the spring of the year. Collins Meadow is reached at a distance of 10 miles from the North Fork. From that meadow the trail to Tehipiti Valley turns south and follows easily along a sloping bench between the saw-tooth Tombstone Ridge on the west and Crown Creek, to the head of the steep descent (2,500 feet in 3 miles) to Tehipiti Basin. The elevation at the top of this steep trail is 6,500 feet and at the bottom 3,950 feet. At the junction of Crown Creek with the Middle Fork, in Tehipiti Valley, and dividing the two creeks, rises sheer from the bottom of the basin, 3,350 feet in elevation, the remarkable Tehipiti Dome.

A survey of the basin was made with enough detail to give roughly the capacity of a reservoir with a dam 150 feet high. The area of the reservoir would be 218 acres and the capacity 10,000 acre-feet. The dam would be 1,000 feet long on its crest. On the west side the material is all loose, being a talus from a high cliff. On the east side some bed rock is visible where a spring torrent has washed out a

channel, but there is no really good dam site. On August 26 the river was measured at a favorable place in the valley and 153 second-feet were recorded.

Having connected the survey with Tehipiti Dome a traverse line was run down the Middle Fork Canyon toward the South Fork junction, to ascertain the fall that would be available for power development. (See profile of river, Pl. XXIII.) The canyon is a difficult one to traverse, and without a very expensive trail the traverse would have been impossible had the water in the river not been low enough to permit the continual crossing and recrossing of the stream. Five miles of the canyon were traversed from the camp at Tehipiti, and this being the limit of walking distance for a day's work, and the junction not being in sight, the camp was moved, by way of the North Fork and the main river, to the junction. A typical view of the canyon of Kings River near the junction of the South and Middle forks is shown in Pl. XXIV, *B*. Pl. XXIV, *A*, is a view looking up the Middle Fork, and shows in the foreground its junction with the South Fork.

Leaving Tehipiti the trail by way of Collins Meadow (elevation 7,600 feet) and Garlic Meadows (elevation 8,000 feet) was taken to the mouth of the North Fork of Kings River (elevation 800 feet), a distance from Tehipiti of 35 miles. By this time the pack animals were in very poor condition from scarcity of feed, owing to the repeated dry seasons, and forage had to be carried up Kings River during all subsequent work. On September 13 the party started a traverse up Kings River from the mouth of Mill Flat Creek, where the Sanger Lumber Company's flume enters the canyon (elevation 880 feet), to the junction of the Middle and South forks, a distance of 14 miles by traverse line and estimated to be 30 miles by trail. The elevation at the junction was found to be 1,950 feet. The junction of the Middle and South forks was reached October 8, after an arduous trip, for a great deal of brush-cutting and considerable pick and shovel work had to be done to get the animals safely over bad places.

The Middle Fork work was continued from 5 miles below Tehipiti and was joined to the main river survey. A traverse line was then started with a view to ascertaining the distance and grade of the South Fork Canyon up to the "hotel." This survey, however, was prevented by an impassable canyon 2½ miles above the junction, and it being near the end of October further exploration work was postponed. On October 20 the river was measured below the junction of the Middle and South forks and a flow of 346 second-feet was recorded. The traverse of the main river developed the fact that from the junction of the Middle and South forks the grade for 14 miles down the river, or to the mouth of Mill Flat Creek, averages 76.4 feet to the mile. For 3 miles below the junction the grade is only 72 feet to the mile. It then increases to a maximum of 103 feet per mile, gradually

A. REFLECTION LAKE.

B. GRANITE BASIN RESERVOIR SITE.

A. OUTLET OF GRANITE BASIN RESERVOIR SITE.

B. CANYON OF MIDDLE FORK ABOVE TEHIPITI BASIN.

lessening, until above Mill Flat Creek for 3 miles it averages 54 feet per mile.

The survey of the South Fork was not finished, but the work that was done warrants the belief that as good a power plant can be developed there as on the Middle Fork. For this reason the site for the power house was chosen on the peninsula between the Middle and South forks (see Pl. XXV), so that either or both could be used. A conduit from the South Fork brought down the North Fork side of the canyon could be taken to the same penstock, if necessary, as the Middle Fork conduit. In any event the site proposed for the power house is in the most advantageous position to utilize water power from both forks. A preliminary estimate was made of the cost of a conduit to carry sufficient water out of the Middle Fork to generate 6,500 horsepower at the junction of the Middle and South forks. The estimate embraces the necessary works from the intake to the penstock. The location on the Middle Fork was selected because of the heavy fall of the stream at that point. The works would be in the canyon of the Middle Fork and would be reached by way of Millwood and the Sanger Lumber Company's road, already described, which runs to within 6 miles of the junction of the Middle and South forks. The descent in those 6 miles is about 3,000 feet, and will require a 10-per cent graded road. To reach the site of the proposed power house a bridge will be necessary across the South Fork and 6 miles of trails will be needed up the canyon of the Middle Fork and around the works. The intake or headworks would be between 3 miles and 3½ miles up the Middle Fork, whence the water will be conveyed in a series of short tunnels with a maximum single length of 1,500 feet. The tunnels will be in granite, unlined, and 6 feet by 6 feet in the clear. Adits in canyons will be arched over, allowing storm water a clear way. This form of construction is not only of a permanent nature, but it requires the minimum hauling of material and supplies into the canyon.

Following is the estimate of cost:

Cost of conduit out of Middle Fork.

Road into canyon, 6 miles at $8,500	$51,0
Bridge across South Fork	2,5
Trails in canyon of Middle Fork, 6 miles at $500	3,0
Tunnels (Burleigh drill work), 14,000 feet at $12	168,0
Headworks, including masonry diverting dam, shaft for inlet, tower, entrance gate, screen, etc	5,0
Adits to tunnels, 14 at $500	7,0
	236,50
Engineering and contingencies, 15 per cent	35,47
Total	271,97

The elevation of the intake would be 2,700 feet, the elevation of the penstock 2,660 feet, and the elevation of the power house 1,980 feet. The available head is 650 feet. The estimated mean minimum horsepower equals

$$\frac{\overset{\text{h.}}{650}\times\overset{\text{s.-f.}}{100}\times\overset{\text{lbs.}}{62.5}}{550}, \text{ or } \frac{650\times100}{8.8}, = 7{,}386.$$

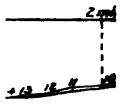
With 150 second-feet passing through the tunnel the horsepower equals

$$\frac{650\times150}{8.8}=11{,}000.$$

With 180 second-feet passing through the tunnel the horsepower equals

$$\frac{650\times180}{8.8}=13{,}300.$$

During the late summer, when Kings River is at its minimum stage, practically all of its water is coming from the higher mountains drained by the Middle and South forks. In dry years the North Fork delivers in September about 10 second-feet, which is perhaps enough to make good the loss by evaporation in the main river from the junction to the Red Mountain gaging station. It is believed that there is as much water at the junction as at Red Mountain. Observations on the main river at Red Mountain covering the months of July, August, and September of the years 1896 to 1900, inclusive, indicate that had the proposed tunnel conduit been in operation during that time it could have been filled to its maximum capacity of 180 second-feet during the whole of the month of July of each year. During the whole of August of the same years the tunnel could have been supplied with 100 second-feet of water, and for 75 per cent of the time it could have had 150 second-feet. During September of the same years a supply of 100 second-feet could have been obtained three-fifths of the



:R CANYON

he lower line

A. MIDDLE FORK OF KINGS RIVER ABOVE JUNCTION OF SOUTH FORK.

B. KINGS RIVER CANYON.

time and an average of 85 second-feet during the remaining two-fifths of the time—the exceptionally dry years of 1898 and 1899. With 650 feet head the 85 second-feet would yield

$$\frac{\overset{\text{h.}}{650} \times \overset{\text{s.-f.}}{85}}{8.8} = 6{,}250 \text{ horsepower.}$$

This means that during every month of each of the foregoing years, excepting the two months of August and September, the conduit could have carried its maximum capacity of 180 second-feet.

Careful measurements should be made of the Middle and South forks to determine their respective volumes of flow before construction is attempted.

GROUND WATER OF KINGS RIVER DELTA.

The territory with a deficient water supply is that covered in the main by the Fowler Switch, the Alta District, the Kingsbury, and the Last Chance canals, Peoples' ditch, and the Fresno canal. A late summer supply would permit the production of alfalfa and other products. The natural drainage of these lands is toward the southwest, at the rate of about 6 feet to the mile. The soil is largely granitic sand, and below an average depth of 10 or 15 feet it is saturated with water. The surface water is somewhat alkaline, and therefore it is not advisable to pump it for irrigation. Water below a depth of 50 feet can be considered satisfactory for irrigation. This is based on tests of more than 800 wells in the district, some of them being in sections where there were the strongest surface alkaline indications. In every case this lower water was found to be good, and when the strata near the surface are penetrated it rises to the elevation stated.

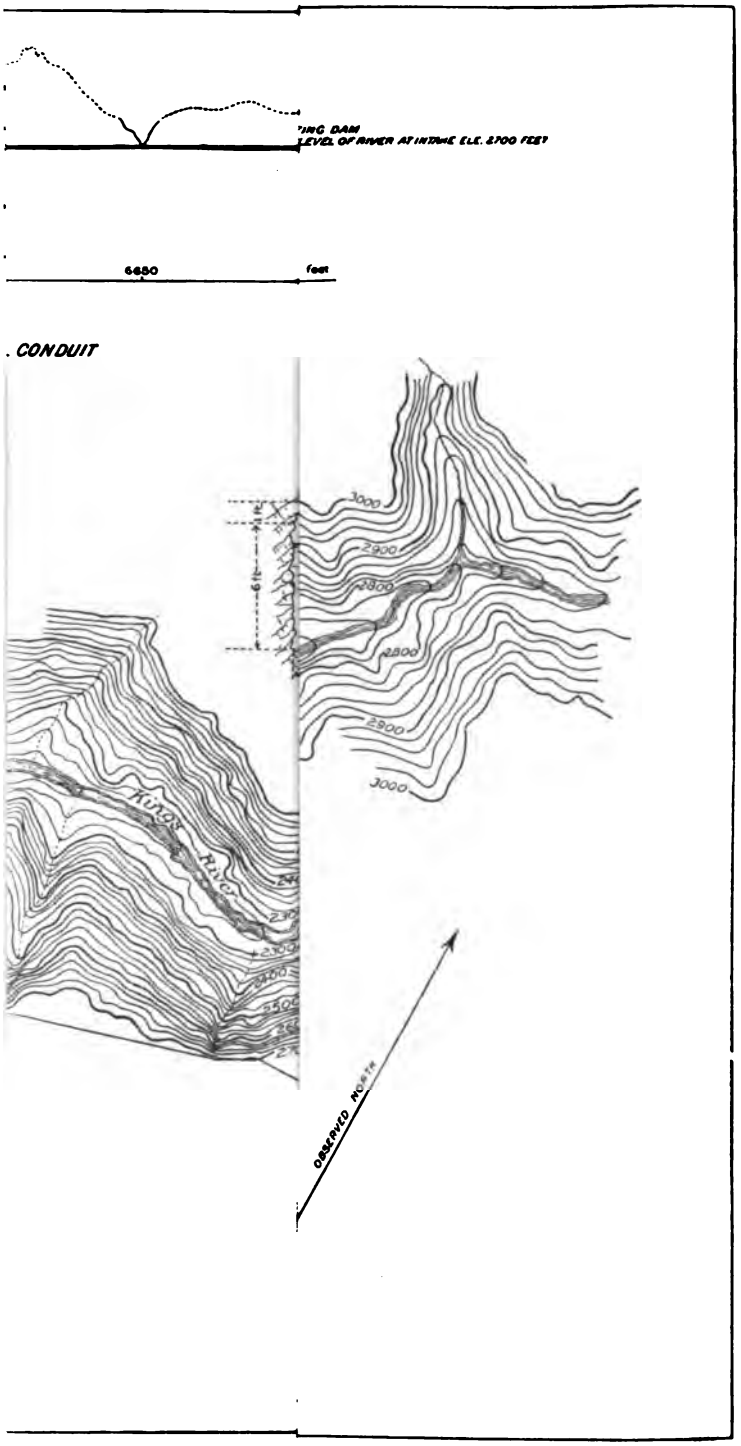
There have been few attempts to pump water in larger quantity than is required for domestic purposes. A 2-inch screw pipe put down to an average depth of 50 feet, landing the pipe on a stratum of clay and then boring through the clay and allowing the water to come in from the bottom of the hole, is always ample for this purpose. Locally it is the common impression that by boring through two or three strata of clay or hardpan all of the surface water is shut off, thus exempting the consumers from one of the supposed causes of malaria. An abundant supply of water at 20 or 30 feet could be obtained, but the quality would not be so good.

One of the largest pumping plants in this vicinity is that of the Fresno Domestic Water Company, the water supply for which is obtained from unperforated wells at a depth of 600 feet. In this case an ample supply (about 4 second-feet) for a city of 12,000 inhabitants is obtained from a city lot 50 feet by 150 feet. In and around Fresno a number of wells have been put down for street sprinkling. These

wells are 8 inches in diameter and do not exceed 70 feet in dep They are unperforated, excepting perhaps the lower joint or two the pipe, and practically all of the water comes from the bott With a 2½-horsepower engine they fill a 1,250-gallon tank 9 feet ab the surface in five minutes, or at the rate of more than 0.5 seco foot, lowering the water plane during the pumping not to exceed 5 6 feet below its normal elevation. A few small pumping plants ha been installed—one 5 miles east of Fresno, on Minnewawa ranc several around Selma, and two near Wild Flower—which yield at les 0.5 second-foot to a 7-inch unperforated well not more than 70 fe deep, with a lift not to exceed 20 feet in any case.

Wells of about 10-inch or 12-inch casing should be put down to depth of about 100 feet on an average, and should not be perforate above 50 feet below the surface, thus shutting off all possible chan of drawing from the more or less alkaline surface water. It is pro able that wells of this size and depth would each furnish 1.5 second feet. A well driller in Selma states that he will put 12-inch well down to a depth of 150 feet and guarantee them to furnish 1.5 second feet each, without perforations, at a cost not to exceed $300 pe well.

Pl. V is a map of Kings River delta showing the distribution canal and the location of the wells visited during the investigation. The numbers of the wells on that map correspond with the numbers in the following table, which gives the details concerning each well. The principal facts regarding the wells are given in abbreviated form. In the first column is the number of the well, as shown on the map, Pl. V. In the next column is the name of the owner, and following that the location, by township, range, and section; the date completed; and the class of well, the latter being indicated by symbol, *D* meaning dug well, *Dr* driven well, and *B* bored well, the accompanying figures giving the average diameter or width, in inches—for example, *D36* means a dug well 36 inches across. The depth of the well, the depth to water, and the depth of the water in the well, all in feet, are given in the next columns. These columns are followed by one giving the character of the strata, which is indicated by initials, *C* meaning clay, *G* gravel, *Gr* decomposed granite, *L* loam, *S* sand, *Q* quartz rock, *Qs* quick-sand, and *Hp* hardpan. To illustrate: *LSG* is equivalent to loam, sand, and gravel. The next column (right-hand page) gives the quality of the water, whether hard, soft, alkaline (*alk*), or sulphurous (*sul*). The next one gives the method by which the water is obtained, the word *hand* meaning hand pump, *horse* a horse-power machine, and *wind* a windmill. In the latter case the accompanying figures give the diameter of the windmill, in feet. For example, *14 wind* is intended to imply that water is pumped by a 14-foot windmill. The cost of the well and of the machinery is given in the next



SHOWING LOCATION OF POWE

two columns. Following that is the character of the supply, *good* indicating a good supply and *small* a small or deficient supply; where the quantity is given it is in gallons per day of twenty-four hours. In the next column, headed "Use of water," the abbreviation *dom* implies domestic use, *st* implies use for watering cattle and horses, and *irr* that water is also used for irrigation. The last column gives the relative salinity of the water in parts per 100,000. As a rule the water in most of the wells varies in quantity as a result of irrigation, the fluctuation being within limits of a few feet.

Wells in Kings River delta—

No. of well.	Owner of well.	Location. T.	R.	S.	Year completed.	Class of well.	Depth of well.	Depth to water.	Depth of water.	Strata.
							Feet.	*Feet.*	*Feet.*	
1	R. A. James	14	23	10	1893	D36	14	12	2	GB
2	L. W. Hobler	14	23	14	1894	Dr2½	14	10	4	GB
3	Mount Camel Vineyard.	14	23	23		D36		12		Gr
4	'76 Company					B4		33		
5	W. S. Goodfellow				1894	Dr1½		10		LSGB
6	E. J. Bullard	13	19	2		B2		65		
7	P. M. Hart	13	20	8		B7				
8		13	20	10		B5				
9	H. Johnson	13	20	3		B				
10	J. H. Funck	13	20	3	1892	B7	80	32	48	
11	H. V. Parker	13	20	10	1891	B8	105	30	75	
12		13	20	11		B5		28		
13	Gus Ploetz	13	21	6	1895	B5	80	28	52	
14	W. M. Shortridge	13	21	5	1897	B5	36	8	28	GCQs
15	R. T. Owen	13	21	8	1881	B7	90	13	77	LHpCG
16	T. L. Hunter	14	20	4	1898	B7	55	5	50	LG
17	Mr. Roeding	13	20	32		B3	60			
18	M. Dunlavey	13	20	33	1895	B5	90	7	83	LG
19	William Shepp	13	20	33	1898	B2	56	9	47	LGCS
20	do	13	20	29		B2		10		
21	J. Mills	13	20	29	1892	B5	80	8	72	LG
22	M. Jensen	13	20	29	1888	B2	85	12	73	
23	J. P. Green	13	20	19	1898	B2	104	14	90	
24	August Bopp	13	20	19	1892	B3	65	15	50	Hp
25	Conrad Bopp	13	20	19	1898	D36	17	16	1	Hp
26	Mrs. E. G. McCardle	13	19	24	1900	B6	96	27	69	SG
27	W. N. Harris	13	20	19	1894	B2		22		
28	E. G. Dickinson	13	20	19	1894	B2	44	20	24	G
29	F. G. Foster	13	20	19	1898	B5	104	28		
30	S. E. Ward	13	20	19	1892	B6	95	25	70	HpS
31	A. S. Coon	13	20	20	1880	B6	125	18	107	
32		13	20	20		B2		16		
33	B. T. Tipton	13	20	20		B6	70	16	54	
34	Wm. N. Fuller	13	20	29	1897	B2	76	6	70	HpSG
35	G. M. Boles	14	20	4	1897	B6	65	6	59	
36	Abraham Wade	13	20	33	1898	B3	70	6	64	
37	Jno. Barry	13	20	34	1895	B2	50	6	44	
38	C. D. Edgerly	13	20	27	1890	B2½	85	10	75	
39	Mr. Bailey	13	20	28	1896	B2	55	9	46	
40		13	20	21		B6		17		
41	T. C. White	13	20	22		B7	50	18	32	
42		13	20	10		B7	40	21	19	
43	J. Wallers	13	20	10	1890	B6	65	24	41	
44	C. W. Stevens	13	20	14	1892	B7		17		
45	Wm. Bitner	13	20	14		B2½		15		
46	H. J. Lorgenson	13	20	14	1892	B2	35			
47	M. J. Miles	13	20	11		B3				
48	Mr. Helm	13	20	12		B7				
49	G. G. Besigger	13	21	19	1891	B6	82	9	73	
50	Jno. Swenson	13	21	19		B	80	8	72	
51	Mr. Wolf	13	21	19		B				
52	Eggars estate	13	21	30	1897	B				
53	Ger. S. and L. Bank	13	21	19		B6		9		
54	C. G. Anderson	13	21	30	1880	B6	53	8	47	G
55	Esmeralda Vineyard Co.	13	20	35	1891	B2	65	7	58	
56		13	20	34		D3x5	9	7	2	
57	Geo. I. Helm	13	20	26		B		7		
58	W. J. Dickey	13	20	25	1892	B7	120	7	113	
59	J. P. Thomas	13	20	25	1884	B2	76	6	70	
60		13	21	30		B		7		
61	E. J. Azbderian	13	21	31		Dr				
62	F. M. Roessler	13	21	30	1890	B2	50	6	44	SLGHpQs
63	G. R. Shipp	13	21	30	1892	B3	83	8	75	
64	Guthrie Co	13	21	31	1890	B	80	6	74	
65	E. Kennedy	13	21	31	1887	B6	72	8	64	
66	Mr. Forsyth	13	21	32		B				
67	Guthrie & Co	13	21	32		B4		7		
68	G. R. Taylor	13	21	33		B	90			
69	Y. Logan	13	21	32		B2	100	7	93	
70	L. L. Desnhar	13	21	32	1884	B	85	6	79	
71	Eggars estate					B8		6		
72	Olsen estate	13	21	19	1899	B6	80	7	73	SLHpCG

[a] Where the quantity is given it is in gallons per day of 24 hours.

Fresno, Tulare, and Kings counties.

Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Supply.[a]	Use of water.	Salts, parts per 100,000.
Soft	Hand			Good	Dom	14
do	do	$10.00		do	do	8
	do				do	10
	Horse				Stock	
Hard	Hand		$4.00		Dom	8
	Wind				Dom; st	12
Soft	do			3,000 gallons	do	11
do	Hand			Good	Dom	8
do	Wind			do	Dom; st	11
do	Hand			do	Dom	11
do	14 wind			2,000 gallons	Dom; st	11
	Hand				Dom	10
Soft	Wind				do	9
do	12 wind	18.00	45.00		do	15
do	Wind			Good	do	11
do	Hand			do	do	11
do	12 wind			do	Dom; st	12
do	Hand		105.00	do	Dom	12
do	do	15.00	1.50	do	Dom; st	10
	do			do	Dom	8
Soft	do	40.00	25.00	do	do	8
do	Wind	34.00	75.00	do	do	10
do	Hand		55.00	do	do	9
do	do	30.00	5.00	do	Dom; st	9
do	Rope			Small	Dom	9
	Hand				do	8
Soft	do		4.00	Good	Dom; st	8
do	do				Dom	8
do	do	75.00		Good	do	8
do	do	45.00	15.00	do	do	8
do	do		6.75	do	do	10
	do				do	
Soft	do		3.00	Good	do	8
do	8 wind	20.00	41.00	do	do	8
do	Wind			do	Dom; irr	12
do	8 wind			do	do	11
Hard	Hand		25.00	do	Dom	10
Soft	18 wind		35.00	do	do	11
do	Hand			do	do	
	Wind				do	8
Soft	do			Good	do	8
do	Hand			do	do	12
do	do		80.00	do	do	11
do	8 wind			do	do	10
do	Hand		5.00	do	do	10
Hard	do			do	do	10
Soft	do			do	do	12
do	14 wind			do	Dom; st	10
do	Hand			do	Dom	12
do	do		5.00	do	do	8
do	do			do	do	8
do	Wind			do	do	12
do	Hand			do	do	8
do	Wind			do	do	8
do	Hand		5.00	do	do	8
	Lever	6.00	1.50	Small	Dom; irr	15
Soft	Wind			Good	Dom	14
do	Gas; hand			do	do	12
do	do		5.00	do	do	10
do	Hand			do	do	8
do	do		5.00	do	do	9
do	Wind			do	do	12
do	do	83.00	170.00	do	do	12
do	do			do	do	13
do	do			do	do	
do	do			do	do	11
do	do			do	do	9
do	do			do	Dom; st	10
do	do			do	Dom	6
do	do	85.00	130.00	do	do	9
do	Steam			30,000 gallons	Winery; dom	13
do	Steam; wind	100.00		Good	do	12

Wells in Kings River delta—Fresno,

No. of well.	Owner of well.	Location. T.	R.	S.	Year completed.	Class of well.	Depth of well. Feet.	Depth to water. Feet.	Depth of water. Feet.	Strata.
73	Paul Leonhart	13	21	19	1889	B1¼	70	9	61	
74		13	21	19		B7		10		
75	S. P. Co	12	19	5	1887	D12 B8	140	85	55	LHpGCS
76	Thornton estate	12	19	34		B8				
77	Lee Cobb	12	19	35		B7				
78	E. J. Bullard	12	20	31	1886	B8		70		HpSGC
79	do	13	20	5		B8		100		
80	J. H. Randel	12	20	34		B6	70	60	10	
81	E. J. Lane	12	20	22	1894	B8	99	85	14	CSG
82	Frank Lane	12	20	15	1886	B		85		
83	J. P. Williams	12	20	14		B6	115	90	25	
84	Sacramento Bank	12	20	13		B6		80		
85	A. B. Ball	12	21	7	1892	B6	145	80	65	G
86	Gudlip Ambrosia	12	20	24	1891	B6		68		
87	Harry Maupin	12	20	25	1885	B6	113	48	65	CGS
88	Geo. Johnson	12	21	19		B5		38		
89	F. E. Brown	12	21	20	1890	B7		34		
90	W. Foster	12	21	19	1892	B7	75			
91	B. F. Parker	12	21	17	1881	B7	93	35	58	CG
92	J. W. Brown	12	21	18	1882	B7	100	45	55	CSG
93	Milo Rowell	12	21	5	1880	B7	130	60	70	
94	J. M. Heiskell	12	21	8	1880	B7	100	63	70	C
95	Chas. Brown	12	21	4	1900	D48		50+		CG
96	Mrs. Birkhead	12	21	4		D48	26	18	8	([a])
97	V. B. Cobb	12	21	9		D54	47+	33	14+	([b])
98	J. M. Heiskell	12	21	10		D-B		22		
99	Fresno National Bank	12	21	15	1889	B8	86	18	68	CG
100	J. H. Barker	13	20	15	1891	B2	60	15	45	
101	F. M. Merrit	13	20	14		B7	100+	14	86	
102	Mr. Moon	13	20	23		B2	45	13	32	
103	Bismarck Vineyard	13	21	29		B2		6		
104	P. H. McGarry	13	21	21	1891	B5	80	6	74	
105	M. F. Tarpey	13	21	21		B2	110	7	103	
106	Mr. Hein	13	21	28		B2		6		
107	Andrew Palm	13	21	15	1891	B2	85	6	79	L
108	G. J. Tyler	13	21	16	1900	B2	81	14	67	L
109	H. J. Clifford	13	21	9	1894	B1¼	80	14	66	
110	C. R. Damon	13	21	8	1898	B5	54	10	44	LHpCG
111	J. W. Sharer	13	21	15	1890	B6	80	9	71	L
112	J. Darnold	13	21	9		B7		8		
113	G. W. Green	13	21	4		B5		9		
114	A. Henderson	12	21	33	1888	B5	77	10	67	
115		12	21	33		B		11		
116		13	21	5	1896	B5	50	15	35	
117		12	21	34		B5		14		
118	Sheppard & Teague	12	21	28		B8		12		
119	Chas. A. Owens	12	21	30	1879	D	90	26	64	
120	H. B. Bissell	12	21	28		B8		12		
121	W. E. Parker	13	21	5	1895	B5	50	12	38	LHpAshSG
122	Cates estate	13	21	2	1894	B7	40	10	30	
123	J. W. Potter	12	21	34	1892	B6	50	12	38	
124	do	12	21	26	1877	B8	60	20	40	G
125	do	12	21	26	1899	B8	50	12	38	
126	do	12	21	35	1873	D60	45	18	27	
127	Miss. schoolhouse	12	21	22		B6		9		
128	T. C. White	12	21	22	1895	D60	14	9	5	
129	T. P. Nelson	12	21	14	1888	B6	25	13	12	LHpC
130	Bank	12	21	11		D60	40	20	20	C
131	Reese estate	12	21	13		B9		13		
132	J. E. Dickerson	12	21	23	1880	B8	50	11	39	
133	J. D. Collins	12	21	24	1880	B6	54	14	40	
134	Clovis Cole	12	22	31		D48	31	25	6	
135	Bank	12	22	31		B6		16		
136	D. C. Sample	12	22	32		D60	40	30	10	
137	do	12	22	29		D48	25	24	1	CHp
138	do	12	22	21		D48	14	12	2	
139	Marvin Simpson	12	22	27	1899	D60	25	24	1	Soil
140	Alfred Beard	12	22	26	1890	D60	18	14	4	Gr
141	do	12	22	27	1893	D60	13¼	6	7¼	QsHpCG
142	Jack Simpson	12	22	22	1898	D60	25	20	5	GCSGr
143	B. Simpson	12	22	14	1890	D60	22	15	7	CGr
144		12	22	34		D60	17	14	3	

[a] Heavy soil and adobe rock.

Tulare, and Kings counties—Continued.

Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Supply.	Use of water.	Salts, parts per 100,000.
Soft	Hand	$30.00	$5.00	Good	Dom	8
do	Wind			do	do	8
do	Steam			3,125 gallons	Dom; boilers of S. P. Co.	9
do	14 wind			Good	Dom; st	9
do	12 wind			do	do	10
do	14 wind			do	do	8
do	8 wind			do	do	11
do	Horse			do	do	13
do	8 wind	145.00	41.00	do	do	12
do	16 wind			do	do	12
do	do			do	do	11
do	Hand			do	do	
do	16 wind			do	do	11
do	do			do	do	12
do	14 wind	113.00	90.00	do	do	11
do	Hand			do	Dom	11
do	Wind			do	Dom; st	9
do	do			do	Dom	10
do	16 wind	100.00	125.00	do	Dom; st	12
do	Wind			do	do	11
do	14 wind		174.00	do	Dom	10
Hard	do			do	Dom; st	13
do	16 wind				do	14
do	Hand		5.00	Small	do	13
do	Rope				do	24
Soft	14 wind			Good	do	12
Hard	11 wind		30.00	do	do	15
Soft	Hand		5.00	do	Dom	11
do	Wind			do	Dom; st	13
do	Hand		5.00	do	Dom	8
do	12 wind			do	do	13
do	Hand	40.00	50.00	do	do	13
	8 wind	33.00		do	Dom; st	13
Soft	Hand		6.00	do	do	15
do	do	25.00	5.00	do	do	10
do	8 wind	25.00	100.00	do	Dom	8
do	Hand	60.00	5.00	do	Dom; st	13
do	do	175.00	18.00	do	do	12
do	do			do	do	8
do	do			do	Dom	13
do	Wind			do	Dom; st	10
do	8 wind			do	do	16
do	Hand		5.00	do	Dom	13
do	do		5.00	do	Dom; irr	11
do	do	22.00	5.00	do	Dom; st	13
do	8 wind			do	Dom	11
do	12 wind			do	Dom; st	9
do	8 wind			do	do	11
do	Hand	37.50	48.00	Small	do	13
do	Wind		5.00	Good	do	13
do	Hand			do	do	11
do	8 wind		35.00	do	do	15
do	Hand		5.00	do	do	13
do	8 wind			do	do	21
do	Hand		5.00	do	Dom	
do	Rope			Small	Dom; st	
Alk	Hand		5.00	do	do	13
Soft	do		5.00	do	do	13
	Horse			Good	Stock	20
Soft	14 wind			do	Dom; st	16
Hard	Hand			Small	do	21
do	16 wind			do	do	
do	Hand			Good	do	21
Soft	8 wind		55.00	do	do	13
Alk	16 wind		25.00	Small	do	28
do	8 wind			Good	Stock	25
Soft	Hand			Small	Dom; st	
Hard	8 wind	50.00	45.00	Good	do	12
do	Hand	9.00	5.00	do	Dom	13
Alk	8 wind	10.00	36.00	Small	Dom; st	18
do	Wind			Good	do	14
Hard	Horse			Small	Stock	

[b] Heavy soil.

Wells in Kings River delta—Fresno,

No. of well.	Owner of well.	Location. T.	R.	S.	Year completed.	Class of well.	Depth of well.	Depth to water.	Depth of water.	Strata.
							Feet.	*Feet.*	*Feet.*	
145	Bank of Sacramento	13	22	2		D36	14	10	4	
146	W. M. Harbison	13	22	10	1882	B6	82	37	45	CHpG
147	T. C. White	13	22	9	1882	B8	75	35	40	
148	C. J. Reyburn	13	22	9	1882	B8		33		
149	Redbanks school-house.	13	22	8		B7		26		
150	A. Gordon	13	22	8		D60	20	14	6	
151	B. F. Griffen	13	22	6	1880	D60	50	28	22	
152	A. H. Hamilton	13	22	7	1875	D60	60	25	35	CHpG
153	Fresno L. and S. Bank	13	22	6	1882	D60	37	18	19	G
154	do	13	22	6	1880	B7		32		G
155	R. G. Hewitt	13	21	14	1892	B2	90	12	78	
156	Sam Ebe	13	22	8		D48		11½		
157	S. F. Bank	13	22	8	1882	D60		21		
158	Sacramento Bank	13	22	8	1880	D48	60	22	38	
159	Jno. Lee estate	13	22	16	1880	B6	60	23	37	
160	J. M. Ellmore	13	22	15	1884	B8	80	37	43	G
161	Alfred Beard	13	22	15	1885	B8	75	38	37	
162	Mr. Gibson	13	22	14	1880	D54		30		
163	Mr. Meyers	14	20	2	1890	B2	30	15	15	
164	County of Fresno	14	20	2	1897	B7		10		
165	J. Nishkian	14	21	6		B2		8		
166	L. Dalton	14	21	6	1892	B2	80	15	65	L
167	J. Steinivaud	14	21	6	1882	B6	45	6	39	LHpCG
168	St. George Winery	14	21	5	1894	B10	300	6	294	
169	W. E. Carrico	13	21	33	1885	B5	78	9	69	LHpGC
170	H. J. Eaton	13	21	33		B2		9		
171	S. E. Mill	13	21	34	1899	B2	70	12	58	G
172	Miss Ethel Shell	13	21	34	1898	B2	79	12	67	LCSG
173	Geo. C. Roeding	14	21	3	1885	B8	90	8	82	G
174	Judge Wallace	13	21	35	1899	B2	45	20	25	S
175	G. B. Passon	13	21	36	1893	B2	40	14	26	
176	M. E. Laymensce	13	21	36	1891	B2	60	8	52	CHp
177	E. L. Curtis	13	22	31		B		7		
178	Mr. Wright	14	22	6	1898	B2	65	10	55	SG
179	R. B. Baird	13	22	32	1900	B2	75	11	64	S
180	Sacramento Bank	14	22	5		B5		9		
181	S. F. Savings Union	13	22	32		B6	85	16	69	
182	W. O. Blasingame	14	22	4		B72	60	10	50	
183	Dr. Chester Rowl	14	22	4	1897	B2	95	14	71	LHpCS
184	Fresno Milling Co.	14	20	3	1897	B2	81	12	69	SLGC
185	Jno. D. Rutledge	14	20	4	1897	B2	75	6	69	SG
186	C. W. Forsman	13	20	34	1888	B2	60			S
187	A. Vogel	13	20	34	1888	B4	60	8	52	SC
188	Mr. Hayes	13	20	35	1882	B7	70	11	59	
189	Joseph Bocarde	14	20	2	1895	B3	75	20	55	LHpQsSGC
190	Mr. Dickerson	13	20	35	1884	B1½		8		
191	J. W. Martin	13	20	35	1888	D2	12	7	5	L
192	G. T. Hawley & Bro.	13	20	35	1895	B2	90	15	75	G
193	San Ricardo Vineyard	13	21	31		B		10		
194	H. M. Rustigian	14	21	6	1891	B2	60	12	48	
195	J. Rustiglan	14	21	6		B2		10		
196	C. D. Wright	14	21	5	1896	B2	80	8	72	
197	Geo. Goodrich	13	21	33		B2	75	7	68	
198	Frank Green	13	21	33	1892	B2	60	9	51	G
199	N. C. Skoegard	13	21	33	1885	B2		8		
200	Alice Treadwell	13	21	34	1887	B2	85	10	75	SG
201		13	21	27	1899	B2		9		
202	L. M. Fincher	13	21	22	1880	B8	75	6	69	CS
203		13	21	15		B2		7		
204	N. A. Shelling	13	21	15		B2		8		
205	E. E. Irwin	13	21	14	1885	B8	85	9	76	CGS
206	W. Davenhill	13	21	14	1894	B2		7		
207	J. D. Reyburn	13	21	11	1892	B7	85	12	73	LHpS
208	Geo. P. Byreborg	13	21	14	1890	B2	90	16	74	GCHpQsCG
209	A. J. Cass	13	21	14	1891	B2	60	9	51	
210	Mr. Herman	13	21	24	1897	B2	40	8	32	CHpCSG
211	McDonald estate	13	22	18	1877	D48	80	15	65	
212		13	22	18		D48		11		
213		13	22	19		B2	17	14	3	
214	Samuel Funck	14	20	3	1890	B1	75	12	63	LHpCSG
215	R. J. Robinson	14	20	3	1900	B2	73	10	63	S
216		14	20	2		B2		10		
217	Thos. Hughes, vin	14	20	11		B		8		
218	D. J. Vaughn	14	20	12	1882	B5	65	9	56	LCSG

Tulare, and Kings counties—Continued.

Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Supply.	Use of water.	Salts, parts per 100,000.
Hard	Hand		$5.00	Small	Dom; st	15
do	10 wind		90.00	Good	do	15
do	Hand		6.00	do	do	12
do	Wind			do	do	12
do	Hand			do	Dom	14
do	Rope				Dom; st	
Soft	8 wind		40.00	Good	Dom	11
Hard	Wind	$50.00	130.00	do	Dom; st	15
Soft	do		14.00	do	do	17
Hard	14 wind			do	do	17
Soft	Hand		5.00	do	do	12
do	do			do	do	14
Hard	Wind			do	do	14
do	do			do	Dom	13
do	8 wind		40.00	do	Dom; st	12
do	10 wind	80.00	165.00	do	do	15
Soft	Wind		85.00	do	do	13
Hard	Rope			do	do	15
do	Hand	15.00	4.25	do	do	12
do	Gas			288,000 gallons	Streets	20
Soft	Hand		4.25	Good	Dom; st	11
do	8 wind	30.00	79.00	do	do	8
do	Hand	40.00	10.00	do	do	8
do	Steam	120.00		120,000 gallons	Winery	11
do	Hand		4.25	Good	Dom; st	8
do	do		4.25	do	do	11
Hard	8 wind	23.00	46.00	do	do	12
Soft	do	23.50	52.00	do	do	11
Hard	Gas			24,000 gallons	Irr; dom	9
Soft	Hand	23.00	5.00	Good	Dom	8
do	8 wind	20.00	75.00	do	do	8
do	Hand			do	Dom; st	8
do	do			do	do	12
do	do	23.00	5.00	do	do	8
do	do	20.00	6.00	do	do	8
do	do		4.25	do	do	8
do	do		6.00	do	do	8
do	do		5.00	do	do	13
do	do			do	do	11
do	do	20.00	4.00	do	do	14
do	do	16.00	4.00	do	Dom	15
do	do			do	Dom; st	14
do	8 wind			do	do	11
do	Hand		6.00	do	do	14
do	do		15.00	do	do	10
do	8 wind		45.00	do	do	8
do	Hand		5.00	do	do	11
Hard	do		4.00	do	do	10
Soft	8 wind		50.00		do	11
do	Hand	25.00	4.00	Good	do	11
do	do			do	do	11
Hard	do		4.00	do	Dom	10
do	do	30.00	4.00	do	Dom; st	8
do	do	30.00	4.00	do	do	14
Soft	do		4.00	do	Dom	8
do	do	40.00	4.00	do	do	10
do	do		4.00	do	do	13
Hard	do		6.00	do	Stock	13
Soft	do		4.25	do	Dom; st	11
do	do		4.00	do	do	8
do	8 wind		65.00	do	do	12
do	Hand		4.25	do	Dom	16
do	12 wind	85.00	125.00	do	Dom; st	15
do	Hand	27.00	4.25	do	Dom	18
do	do	30.00	8.00	do	do	16
	do	12.00	6.00	do	Dom; st	12
Soft	Rope			do	do	
do	do			do	do	
do						
do	8 wind	22.00	100.00	Good	Dom	13
do	Hand	29.00	4.25	do	do	11
do	do		4.00	do	Dom; st	12
do	8 wind			do	do	12
	Wind	45.00	9.00	do	Dom	8

Wells in Kings River delta—Fresno,

No. of well.	Owner of well.	Location. T.	R.	S.	Year completed.	Class of well.	Depth of well.	Depth to water.	Depth of water.	Strata.
							Feet.	*Feet.*	*Feet.*	
219	A. B. Butler	14	21	7		B7		9		
220	Hughs Richler	14	21	6	1880	B2	40	10	30	CS
221	Fresno Vineyard Co.	14	21	7		B6		9		
222	J. Rogers	14	21	8		B8		8		
223	Fred Roeding	14	21	2	1887	B7	110	17	93	
224	Bonner Vineyard Co.	14	21	11	1885	B8	104	14	90	LHp
225	A. F. Albrecht	14	21	1	1899	B2	54	8	46	CS
226	Judge Risley	14	22	6	1893	B2	90	18	82	CS
227	Fresno Bank	14	22	5		D36	14	10	4	
228	John Crol	14	22	9	1892	B6	50	17	33	CSHp
229	M. J. Roeder	14	22	9	1892	B1½	20	16	4	
230	Cora Wickersham	14	22	3	1880	B7		14		
231	F. P. Wickersham	14	22	3		B2		14		
232	Mr. Burness	14	22	3		B6	18	25	3	
233	Jno. Snyder	13	22	35	1897	B7	65	20	45	S
234	Chas. Lyman estate	13	22	34	1880	B7	80	0	60	
235	R. W. Edmiston	13	22	31	1898	B2	100	5	95	LHpCSG
236	do	13	22	30	1890	B2	45	18	37	CLHpS
237		13	22	31	1899	B2		0		
238	Kutner School	13	22	30		B2		9		
239	Victor Marten	14	20	9	1897	B2	82	10	72	S
240	J. H. Hass	14	20	16	1890	B2	70	8	62	
241	Mr. Keamey	14	20	7		B		7		
242	J. J. Luce	14	19	12	1886	B2	72	8	64	
243	Dr. A. E. Small	14	19	12	1890	B2		7		
244	Andrew Nelson	14	19	11	1891	B2	60	8	52	CHpG
245	Kearney estate	14	19	10	1890	B2.5		8		
246	Dolph Shields	14	19	14	1890	B2		9		
247	M. Koller	14	19	15	1890	B2	68	10	58	L
248	F. M. Burnham	14	19	10	1889	B2	73	8	65	LHpCS
249	Maddison School	14	19	12	1897	B2	93	6	87	LHpCG
250	T. H. Burgess	14	19	15	1898	B2	90	8	82	SGC
251	W. W. Underhill	14	19	10	1894	B2		8		
252	S. J. Walton	13	19	34	1900	B8	55	10	45	HpCSG
253	Oscar Carlson	14	19	2	1891	B2	35	6	29	LHpC
254	C. D. Smith	14	19	2	1890	B3	70	8	62	SQsS
255	Mrs. H. L. Granger	14	19	2	1891	B2	55	7	48	SC
256	N. H. Fuglsang	14	19	2	1893	B2	80	7	73	
257		13	19	35		B2		9		
258	Balfour, Guthrie & Co.	13	19	36	1880	B5	30	17½	12½	
259	Lew Showyer	14	19	1	1899	B2		8		
260	Mrs. C. B. Lyman	14	19	1	1900	B6	97	9	88	LHpSC
261	O. D. Garrison	14	20	21	1888	B2	120	8	112	CG
262	E. Tommasini	14	20	29	1897	B2	82	12	70	LHpS
263	M. Robison	14	20	32	1890	B2	70	10	60	SCG
264	G. C. Cheuvraut	14	20	33	1892	B2	75	6	69	S
265	N. Jansen	15	20	5	1889	B2	50	10	40	S
266	J. Gowanlock	15	20	8	1890	B2	60	10	50	
267		15	20	9		B2		12		
268	Dickerson	15	20	9	1885	B2		10		
269	Mrs. L. Walker	15	20	9	1890	B2	60	10	50	Hp
270	Sonensen	15	20	15		B2		12		
271	John Smith	15	20	21	1890	B2	35	10	25	S
272	Bank	15	20	34		B6	50	12	38	
273	Stevens & Harland	15	20	33		B6	+50	16	+34	
274	do	16	20	3		B5	+50	15	+35	
275	Sacramento Bank	16	20	15	1890	B6		12		
276	White	16	20	16		B6	24	16	8	
277	Geo. B. Zigler	16	20	22	1899	B6		17		
278	David Crawford	16	20	33	1887	B6	80	18	62	LHpS
279	McDonald	17	20	4		B6	39	6	33	
280	Geo. Magn	17	20	5		B6		10		
281	Lone Sav. Bk. Co	17	20	4	1886	B6	104	10	94	S
282	Lewis Gibbons	17	20	6	1880	B5	118	10	108	LHpSGC
283	John Walker	17	20	7	1880	B8	75	8	67	SQs
284	Fred Coleman	17	20	8	1893	B6	27	7	20	S
285	Elisha Harlon	17	20	18	1890	B5	70	8	62	LCS
286	Lewis Gobbi	17	19	13	1892	Dr7	20	7	13	S
287	Ger. Savings Bk	17	19	13	1893	Dr1½	15	10	5	S
288	Wm. Bullard	17	20	6		B		14		
289	Chas. S. Pierce	16	20	31	1890	B6	45	12	33	S
290	Capt. Cuttle	16	19	36	1880	B	75	14	61	
291	Mrs. H. Worswick	17	19	1	1890	B6	68	10	58	SC
292	Fred Eaton	16	19	34	1892	B5	72	15	57	S

Tulare, and Kings counties—Continued.

Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Supply.	Use of water.	Salts, parts per 100,000.
Soft	Hand			Good	Dom; st	8
do	do	$16.00	$4.25	do	do	11
do	Gas			do	do	10
do	do			do	do	10
do	14 wind			do	Dom	15
do	Horse	100.00	100.00	do	Dom; st	12
do	Wind; hand	25.00	4.00	do	Dom	11
Hard	Hand	25.00	4.00	do	Dom; st	10
do						10
Soft	Hand	55.00	4.00	Good	Dom; st	
do	do	11.00	4.00	do	Dom	12
Hard	8 wind			200 gallons	Dom; st	12
Soft	Hand		4.00	Good	do	12
do	do	20.00	5.00	Small	do	
Hard	do	20.00	4.00	Good	do	9
Soft	do		4.00	do	Dom	8
do	8 wind	35.00	250.00	do	Dom; st	13
do	Hand	20.00	40.00	do	Dom	
do	do		4.00	do	Dom; st	
do	do		4.00	do	do	11
do	8 wind		200.00	do	Dom	17
do	do			do	Dom; st	8
do	Hand		4.00	do	do	9
do	do			do	do	8
do	do		4.00	do	Dom	18
do	do	25.00	4.00	do	Dom; st	12
Hard	do		4.00	do	do	15
do	do		4.00	do	do	12
Alk	Wind	28.00	66.00	do	do	10
Hard	Hand	29.00	4.00	do	Dom	11
Hard; alk	8 wind	33.00	38.00	do	do	13
Soft	do	29.00	41.00	do	Dom; st	11
do	Hand		11.00	do	do	12
do	Horse	38.00	47.00	do	do	11
Alk	Hand	14.00	4.00	do	Dom	14
Soft	8 wind	42.00	50.00	do	Dom; st	13
Alk	Hand	22.00	4.00	do	do	20
Hard	do		11.00	do	Dom	8
	do		4.00	do	Dom; st	
Alk	do		4.00	do	do	11
Hard	do		4.25	do	do	10
Alk	8 wind	60.00	270.00	do	do	12
Soft	do	48.00	4.25	do	Dom	13
Hard	Hand		26.00	do	Dom; st	29
do	do		3.00	do	do	20
do	do	25.00	4.00	do	do	26
do	do		4.00	do	do	27
Hard; alk	do	25.00	4.00	do	do	37
Hard	Wind		6.00	do	do	16
Hard; alk	Hand		4.00	do	do	89
Hard	do	24.00	4.00	do	do	26
do	do		4.00	do	do	33
Alk	do	15.00	6.00	do	do	35
do	do		4.00	do	do	8
Hard	do		4.00	do	do	
Alk	Wind			do	do	24
do	Wind; hand			do	do	23
Hard	Hand		4.00	do	do	11
Soft	Wind			do	Dom	11
do	do	65.00	14.00	do	Dom; st	9
Hard	Hand		4.00	do	do	13
do	do		5.00	do	do	16
Soft	do		10.00	do	Dom	15
Hard	8 wind	95.00	45.00	do	Dom; st	18
Soft	Hand		25.00	Small	Dom	36
do	12 wind	23.00		Good	Dom; st	45
do	do	70.00	140.00	do	do	10
Hard	Hand	5.00	4.00	do	do	14
do	do	4.00	6.00	do	do	23
do	do		4.00	do	do	24
Soft	Wind	45.00		do	do	12
Hard	14 wind			do	do	35
do	Hand	50.00	4.00	Small	do	34
do	10 wind	51.00		Good	do	23

Wells in Kings River delta—Fresno,

No. of well.	Owner of well.	Location. T.	R.	S.	Year completed.	Class of well.	Depth of well.	Depth to water.	Depth of water.	Strata.
							Feet.	*Feet.*	*Feet.*	
293	Mrs. M. J. Hatch	16	19	34	1890	B5	48	15	33	S
294	Mrs. W. M. F. Jenkins	16	19	34	1886	B	130	14	116	
295	Elkhorn School	17	19	10	1896	B6	100	9	91	
296	Mrs. M. J. Hatch	17	19	10	1884	B5	34	10	24	CS
297		16	19	25		B6	25	20	5	
298		16	19	24		B5	+50	18	+32	
299	G. Kowser	16	20	20		B5	42	17	25	
300	Mrs. M. Sloan	16	20	20		B		16		
301	S. F. Bank	16	20	7	1888	B7	+30	20	+10	
302		16	20	7		B5	+21	14	7	
303	S. F. Bank	15	19	36		B6	36	10	26	
304	John Smith	15	19	25		B5		13		
305	John Rottger	15	19	13		B3		8		
306	C. A. Hager	15	19	12	1890	B		8		
307	R. L. Epperson	14	19	36	1894	B2	60	8	52	S
308	R. L. Dunham	14	19	36	1900	B2	44	8	36	SLHp
309	C. J. Smith	14	20	30	1896	B2	+20	7	13	S
310	Mr. Parker	14	19	25	1898	B2	70	6	64	S
311		14	19	15		B8		7		
312	Herman Boyce	14	19	23		B2		8		
313	August Weye	14	19	27	1881	B6	+80	7	73	LSC
314	Burley Bros	14	19	27	1887	B7	65	8	57	S
315	F. Duhring	14	19	34	1887	B6		8		
316	A. Christian	15	19	10	1890	B2	100	9	91	
317	J. W. Creelman	15	19	10	1890	B6		10		
318	Mike Andres	15	19	14	1890	B2		10		SC
319	Geo. Keslang	15	19	14	1891	B2	65	10	55	SC
320		15	19	27		B5	+50	16	+34	
321		16	19	3		B5	30	19	11	
322		16	19	2		B5	20	19½	½	
323	Louis Montego	16	19	1		B5	+50	17	+33	
324	A. B. Trautwein	16	20	6	1891	B2	150	12	138	
325	D. W. Smith	15	20	31	1887	B7	80	12	68	SHp
326		15	20	32		B8	20	15	5	S
327	G. A. Pell	15	20	26	1890	B2	60	12	48	SCHp
328	C. Nelson	15	20	26		B2	54	12	42	
329		15	20	36		B5		10		
330		15	20	36		B2		12		
331	E. R. Haycroft	16	21	6		B6	50	12	38	
332	C. M. Rasmussen	16	21	6	1885			12		
333	Bank	16	20	13		B		14		
334	Wm. Gibson	16	20	24	1880	B6	26	12	14	SLHp
335	J. H Hudson	16	20	25	1880	B5	60	12	48	
336		16	20	25		B5	20+	10	10+	
337	Wm. Gibson	16	21	31		B5		10		
338	Levi Garret	16	22	26	1880	B6		15		
339	Cemetery	16	22	27		B5		13		
340	C. H. Van Horn	16	22	28	1893	B5	82	12	70	SHpC
341	Mrs. S. M. Smith	14	20	15	1899	B2	90	10	80	S
342	F. Burnham	14	20	36	1882	B6	50	8	42	SHpC
343	H. U. Carver	14	20	36		B2		8		
344		15	30	1		B6		10½		
345		15	20	1		B2		10		
346	J. F. Ward	15	20	12	1888	B2	90	8	82	
347	Fresno Nat. Bk	14	20	36	1890	B2	94	8	86	SHpL
348	Y. Maglio	14	20	36	1890	B2		8		
349	J. F. Cartright	14	20	35		B2		8		
350		14	20	34		B2		8		
351	Geo. A. Coughell	14	20	34	1885	B2	40+	8	32+	SHp
352	Henry Brooks	15	20	3	1885	B2	80			S
353	Jacob Fisher	15	20	3	1885	B6	83	9	74	CS
354	Gus. Johanson	15	20	10	1890	B2		10		S
355	N. M. Nelson	15	20	10		B2	75	10	65	
356	A. Buckland	15	20	11	1881	B5	51	8	43	SHp
357	S. Nelson	15	20	14	1894	Dr2	20	8	12	S
358		15	20	23		B1		8		
359	Philip Koekler	15	20	26	1897	B2	60	12	48	
360	Schoolhouse	15	20	25		B2		10		
361		15	21	19			(a)	(a)	(a)	
362	Dexter & Payne	15	21	19	1890	B1½		10		
363	C. B. Scott	15	21	20	1895	B2	60			
364	W. A. Mills	15	21	16	1900	B5	48	14	34	S
365	Mo. Vineyard Co	15	21	9	1890	B4	60	11	49	
366	S. J. Goree	15	21	8	1891	B4	60	10	50	S

[a] Swale water 10 feet below.

Tulare, and Kings counties—Continued.

Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Supply.	Use of water.	Salts, parts per 100,000.
Hard	12 wind			Good	Dom	8
do	Hand		$4.00	do	Dom; st	8
do	do			do	Dom	11
do	12 wind	$30.00		do	Dom; st	36
	Hand	25.00	5.00	do	do	
	do		5.00		do	
Hard	do		5.00	Good	do	11
Hard; alk	Wind			do	do	18
Soft	16 wind			do	Dom	11
	Hand		4.00	do	Dom; st	10
Hard	Hand			Good	Dom; st	11
do	do		4.00	do	do	
do	do		4.00	do	do	8
Soft	do	24.00	4.00	do	Dom	16
do	do	19.00	4.00	do	Dom; st	16
do	do		4.00	do	do	23
do	do		4.00	do	do	12
Hard	12 wind			do	do	15
Soft	Hand		4.00	do	do	18
do	Horse; wind	60.00	120.00	do	do	14
do	8 wind	43.00	60.00	do	do	16
Hard	Hand		4.00	do	Dom	16
Soft	14 wind	40.00	95.00	do	Dom; st	28
Alk	Hand			do	do	37
do	do			Small	do	20
Hard	do	25.00	4.00	Good	do	20
do				do	do	
					do	
				Small	do	
Soft				Good	do	
do	8 wind		35.00	do	do	8
do	10 centrifugal	100.00		do		9
do	Hand		5.00	do	Dom; st	
do	10 wind	24.00	47?50	do	do	18
Hard	Hand	22.00	4.00	do	do	10
do	do		5.00	do	do	16
do	do		4.00	do	do	11
Soft	do	62.00	4.00	do	do	16
do	do		4.00	do	do	26
do	Wind			do	do	11
do	Hand	26.00	4.00	do	Dom	8
do	do		4.00	do	do	20
do	do		4.00	do	Dom; st	
do	8 wind			do	Stock	
	Wind			do	Dom; st	18
Alk	do			do	Irr	11
Soft	10 wind	41.00		do	Dom; st	11
do	Hand	36.00	4.00	do	do	
do	do		4.00	do	do	12
do	do		5.00	do	do	14
do	do		4.00	do	do	13
do	do		4.00	do	do	13
Hard	do	36.00	4.00	do	do	8
Alk	Wind	37.00	72.00	do	do	10
Soft	Hand		4.00	do	do	9
	do		4.00	do	Dom	
	Wind			do	Dom; st	11
Soft	Hand		4.00	do	do	14
	do	32.00	4.00	do	do	19
Soft	12 wind	70.00	115.00	do	do	14
do	Hand		4.00	do	do	9
do	do		4.00	do	do	19
do	do	46.00	4.00	do	do	12
do	do	8.00	4.00	do	do	8
do	do		3.00	do	do	15
do	do	25.00	46.00	do	do	10
do	do		4.00	do	do	11
Soft	Wind; hand			Good	Dom; st	16
do	Hand	25.00	4.00	do	do	14
Hard	do	30.00	4.00	do	do	11
Soft	do	30.00	11.00	do	do	11
do	do	24.00	4.00	do	do	11

Wells in Kings River delta—Fresno,

No. of well.	Owner of well.	Location. T.	R.	S.	Year completed.	Class of well.	Depth of well.	Depth to water.	Depth of water.	Strata.
							Feet.	*Feet.*	*Feet.*	
367	John Morgan	14	20	16	1890	B2		16		
368	L. A. Gould	14	20	16	1890	B2	80	7	73	
369	T. H. Mallory	14	20	21	1900	B2	69	10	59	SHp
370	W. A. White	14	20	27	1900	B2	57	10	47	CHpSC
371	H. Roff	14	20	27	1897	B2	80	10	70	S
372	do	14	20	33	1880	B8	90	9	81	
373	Richard White	14	20	33	1884	B8	52	6	46	SCG
374	Geo. B. Rowell	15	20	3	1881	B8	94	10	84	S
375	Robt. Boot	15	20	2	1880	B6	90	12	78	CS
376	A. J. Rudy	15	20	2	1898	B2	75	11	64	SC
377		14	21	31		B2		10		
378	A. A. Smith	14	21	32	1890	B2		12		
379	H. M. Eddy	14	21	33	1887	B2	65	9	56	SC
380	R. E. Oliver	15	21	3	1899	B5	29	16	13	S
381	Wylie M. Giffen	15	21	2		B5		12½		
382	do	15	21	12	1880	B		20		
383	J. M. Pugh	15	21	11	1882	B5	42	12	30	SCHp
384	W. O. Edgerly	15	21	13	1880	B6		11		
385	Wm. Dosdon	15	21	24	1894	B2	60	15	45	SCHp
386	J. A. T. Peterson	16	22	7		B5		13		
387	Mrs. C. A. Hammer	16	22	18	1896	B5	40	12	98	SHp
388	S. J. Pelton	16	22	19	1888	B5	86	10	76	
389	Mr. Wilker	16	22	30		B		12		
390	J. C. Bell	16	22	29	1880	B5	54	9	41	S
391	Eschol School	16	22	32	1895	B2	45			CS
392	J. W. Ryce	16	21	36	1886	B5	106	10	96	LS
393	Sacramento Bk	16	22	32	1875	B5	35	10	25	S
394	do	17	22	4	1875	B5	50	10	40	
395	do	17	22	4	1888	B5	50	15	35	
396	Laguna de Tach	17	22	3	1895	B5	107	12	95	
397	S. P. Co	16	22	36	1891	B3	50	20	30	HpS
398	Mrs. M. A. Cowan	16	22	22	1895	B2		15		S
399	John Clark	16	22	28		B5		14		
400	Larse Anderson	16	22	21	1888	B5	60	21	39	SHp
401		16	22	20		B1½		13		
402	W. T. Prather	16	22	17	1880	B6		15		SHpC
403	A. J. Allen	16	22	10	1870	B5	90	16	74	SCHp
404	T. C. Clayton	16	22	3	1893	B5	102	15	87	S
405		15	22	33		B		15		
406	F.-C	15	22	27		B		16½		
407	F. P. Wall	15	22	22	1894	B1½	60	17	43	SHp
408	A. Proctor	15	22	22		B2		13		
409		15	22	20		B2		17		
410	Charley Woods	15	22	9	1885	B5		13		
411	Ben Swanson	15	22	9	1890	B2		16		
412	A. T. Wilkinson	15	22	5	1889	Dr1½	30	18	12	SCHp
413		14	22	29			(a)	(a)	(a)	
414	S. A. Tyler	14	22	32	1900	B8	75	15	60	SCGHp
415	A. Hall	14	22	30	1880	B8		14		
416	Chas. Preuss	14	22	19	1892	B5	38	12	26	HpCS
417	Fresno L. and S. Bk	14	20	14	1880	B6	65	8	57	S
418	Estrella de Ora Drying Co.	14	20	13	1891	B2	75	5	70	CS
419	St. George Vineyard	14	21	17		B8		10		
420	M. E. Sherman	14	21	17	1899	(2 wells) B6	40 120	10	30 110	SHp
421		14	21	21		B8		13		
422	Lone Star School	14	21	22	1897	B2	60	12	48	SG
423	A. C. Funch	14	21	22	1895	B2	80	12	68	SC
424	A. Malter	14	21	27	1894	B2		12		
425		15	21	10		B2		10		
426		15	21	9			(b)	(b)	(b)	
427	A. R. Brown	15	21	10	1900	B5	54	12	42	CS
428	W. R. Shannon	15	21	14	1890	B5	52	11	41	CSHp
429	A. Harris	15	21	23	1881	B5	100+	14	86+	HpS
430	Mrs. C. E. Gower	15	21	27	1894	B5	85	14	71	SHpC
431	M. Leeper	15	21	34	1887	B2	60	14	46	SHpC
432	W. J. Zimmerman	15	21	34	1899	B6	28	12	16	SL
433	Fresno L. and S. Bk	15	21	34	1888	B5	100+	12	88+	
434	J. B. Galbreath	15	21	28		B6		14		
435	J. C. Long	15	21	28	1892	B	80	12	68	SHp
436	Len Lhung	15	21	15	1899	B	90	15	75	
437	H. A. Ross	15	21	2	1898	B5	60	12	48	SG
438		15	21	2-3			(c)	(c)	(c)	

[a] Slough water 15 feet below. [b] Swale water 10 feet below.

Tulare, and Kings counties—Continued.

Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Supply.	Use of water.	Salts, parts per 100,000.
Soft	Hand		$4.00	Good	Dom; st	12
do	Wind	$40.00	150.00	do	do	13
do	8 wind	28.00	300.00	do	Dom	13
Hard	do	225.00	45.00	do	Dom; st	73
Soft	Hand	32.00	4.00	do	do	15
Hard		80.00		do	do	16
	Hand	52.00	4.00	do	do	9
Soft	Wind	94.00		do	do	18
Hard	Hand	90.00	4.00	do	do	15
Soft	do			do	do	12
do	do		4.00	do	do	21
Hard	Turbine			do	Dom	15
Soft	Hand	65.00	25.00	do	Dom; st	11
do	do	21.00	4.00	do	do	16
do	do		5.00	do	do	12
Hard	do			do	do	27
Soft	Wind	26.00	14.00	do	do	13
do	Hand		4.00	do	do	26
do	8 wind	27.00	40.00	do	do	11
do	Hand		12.00	do	do	
	do	40.00	12.00	do	do	11
Hard	do			do	do	24
do	do		4.00	do	do	23
	10 wind	50.00		do	Stock	21
Soft	Hand	18.00	4.00	do	Dom	9
Hard	do	36.00	4.00	do	Dom; st	
Soft; alk	do	35.00	4.00	do	do	10
Hard	do		4.00	do	Dom	23
Soft	do	37.00	5.00	do	Dom; st	30
do	do		4.00	do	Dom	8
Alk	do		4.00	Small	Dom; st	8
Soft	do		4.00	Good	do	8
do	do		4.00	do	do	14
do	do	30.00	4.00	do	do	14
Soft	Hand		4.00	Good	Dom; st	13
do	8 wind		58.00	do	do	9
do	do	90.00	60.00	do	do	10
do	Hand	51.00		do	Dom	9
do	do		4.00	do	Dom; st	13
do	do			do	do	16
do	do			do	do	19
do	do		4.00	do	do	12
do	do		4.00	do	do	
do	do		4.00	do	do	14
Hard	Wind			do	do	20
Soft	do	15.00	40.00	do	do	12
Soft	Wind			Good	Dom; st	15
do	Hand		4.00	do	do	8
do	do	19.00	80.00	do	do	11
do	Wind	65.00		do	do	9
do	Hand			do	Dom	12
do	do		6.00	do	Dom; st	12
do	Steam	206.00	1,300.00	1,292,633 gallons	Irr	9
do	Hand		5.00	Good	Dom; st	15
do	do	24.00	4.00	do	do	13
do	do	25.00	5.00	do	do	15
do	8 wind			do	do	16
do	Hand			do	do	12
Soft	Wind	30.00	4.00	Good	Dom; st	16
do	Hand	26.00	11.00	do	do	12
do	do	75.00	11.00	do	do	12
do	10 wind	75.00		do	do	9
do	8 wind	40.00	117.50	do	Dom	9
do	Hand	17.00	3.25	do	Dom; st	9
Hard	do		3.25	do	do	14
Soft	Wind			do	do	8
do	do	60.00	100.00	do	do	17
	do			do	Dom	12
Hard	Hand	45.00	4.00	do	Dom; st	29

[a] Swale water 15 feet below.

Wells in Kings River delta—Fresno,

No. of well.	Owner of well.	Location. T.	R.	S.	Year completed.	Class of well.	Depth of well.	Depth to water.	Depth of water.	Strata.
							Feet.	*Feet.*	*Feet.*	
439		14	21	35		B2	34	16	18	
440	M. Wash	14	21	27		B5		13		
441	M. J. Driver	14	20	22	1883	B7	40	15	25	LHpSC
442	E. F. Ball	14	20	14	1893	B6	85	13	62	
443	T. -I	14	20	14		B		12		
444	Mrs. F. C. Ketchum	14	20	13	1890	B2	60	12	48	
445	C. N. Brenenfeld	14	21	20	1895	B2	80	9	71	SCHp
446	Jas. Rutheford	14	21	21	1891	B2	100	9	91	CHpS
447	I. D. Garrison	14	21	29		B2		8		S
448	J. W. Scott	14	21	29	1897	B2	60	7	53	S
449	E. R. Bates	14	21	19	1890	B2	82	10	72	
450	J. H. La Ru	14	21	32	1886	B5	50	8	42	SC
451	John Oed	14	21	33	1885	B		10		
452	W. H. Martin	14	21	26	1890	B2		14		
453		14	21	36			(a)	(a)	(a)	
454	Mrs. J. J. Owen	14	22	31	1898	B5	48	13	35	SC
455	D. W. Butler	14	22	31	1898	B5	60	11½	48½	SHpC
456	Dr. A. D. Wilson	15	21	12		B5		11		
457	F. Lemon	15	21	13		B5		13		
458	Mr. Scott	15	21	13		B		15		
459	T. M. Boyd	15	22	17	1881	B5	60	13	47	LSC
460	Geo. West & Son	15	22	29	1900	B8	120	16	104	SCHp
461	Mrs. L. Vance	15	22	31	1885	B5	75	15½	59½	S
462	C. T. Pierson	16	22	6	1890	B2	80	12	68	
463	S. Y. Gordon	16	22	7	1882	B5	108	10	98	SHpC
464	J. C. Hinkle	16	21	11	1890	B5	40	8	32	SCHp
465	D. Shiflet	16	21	10	1890	B5		12		S
466	T. E. Finerty	16	21	4	1885	B5	80	16	64	SCHp
467	H. Craven	16	21	9	1894	B5	50	14	36	S
468		16	21	7-8			(b)	(b)	(b)	
469	Harry Weher	16	21	18		Dr1½	12	10	2	S
470	Sacramento Bank	16	21	18	1890	B6	30	10	20	S
471	H. Maguire	16	21	19		B5		8		S
472	David Heishie	16	21	20	1888	B5		8½		S
473	J. J. D. Barish	16	21	20	1894	Dr½	16	8	3	S
474	J. G. Burnett	16	21	30	1890	B4	25	7	13	SC
475		16	21	31		B5	20	15	5	S
476	Roza Breiza	16	21	29		B5		10		
477	Lee Burton	16	21	28	1880	B4	70	10	60	
478	Martin Elder	16	21	35	1898	B8	52	8	44	SCHp
479	T. G. Martin	16	21	26	1899	B10	50	8	42	LHpSC
480	Will Pickard	16	21	36	1892	B5		10		
481		16	21	24		B5		10		
482	C. S. Campbell	16	21	24	1882	B5	60	9	51	SCHp
483	Sacramento Bank	16	21	12	1880	B5	75	12	63	SCHp
484	Jno. H. Hoffman	16	21	1	1894	B5	35	12	23	S
485	C. E. Roberts	16	21	1	1898	B5	60	14	46	SCHp
486		15	21	35 / 36		¼ by 1/16 mi.	(c)	(c)	(c)	
487	Mr. Vogel	15	21	35		B2		15		
488	Edwin Bullock	14	20	25	1899	B	70	12	58	SCHp
489	F. G. J. Schmidt	14	20	23	1896	B2	40	10	30	
490		15	21	6			(d)	(d)	(d)	
491	F. H. Mills	15	21	5	1890	B5		13		
492		15	21	7			(a)	(a)	(a)	
493	J. V. Lamore	15	21	18	1885	B2	60	12	48	SHp
494	J. B. Perrin	15	20	12	1882	B5	22	13	9	SLHp
495	T. E. Elliott	15	21	18	1890	B2		12		
496	Chas. K. Kirby	15	21	18	1882	B5		12		
497	Mr. Madden	15	21	29	1885	B5	100	12	88	
498	Jno. K. Kennedy	15	21	30	1894	B5	96	13	83	SHp
499		15	21	30			(c)	(c)	(c)	
500	Harland & Stevens	15	21	31	1885	B5		14		
501		16	21	6			(d)	(d)	(d)	
502	Thos. Hansen	16	21	5	1893	B5		14		
503		15	21	32			(a)	(a)	(a)	
504	Robt. E. Hall	16	21	4	1890	B5	100	14	86	HpCS
505		16	21	4-5 / W. ½			(c)	(c)	(c)	
506	Sacramento Bank	16	21	8	1892	B5		20		
507	Terry School	16	21	10		B5		10		
508	Mr. Johnson	16	21	10		B5		10		
509	Jno. Reynolds	16	21	14	1892	B5	60	9	51	SCHp

[a] Swale water 12 feet below. [b] Swale water 15 feet below.

Tulare, and Kings counties—Continued.

Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Supply.	Use of water.	Salts, parts per 100,000.
Soft	Hand			Good	Dom; st	
do	do		$4.00	do	do	12
do	do		12.00	do	do	13
do	Wind			do	do	13
do	Hand		4.00	do	do	12
do	do	$24.00	4.00	do	do	8
do	do	25.00	5.00	do	do	9
Hard	do	40.00	3.00	do	Dom	11
Soft	do		4.00	do	Dom; st	16
do	do	24.00	3.00	do	do	13
do	8 wind		250.00	do	do	16
do	10 wind	40.00	75.00	do	do	19
do				do	do	13
	Hand		3.25	do	do	15
Hard	Wind	26.00		Good	Dom; st	16
	Hand	23.00	3.25	do	do	21
Hard	Wind			do	do	24
Soft	Hand			do	do	10
do	do		4.00	do	do	15
do	do	60.00	11.00	do	do	
do	Steam	132.00		120,000 gallons	Winery	8
	Hand		3.25	Good	Dom; st	15
Hard	do		3.25	do	do	25
Soft	do	86.00	12.00	do	do	10
do				do	do	11
do	Hand			do	do	14
do	Hand	80.00	3.25	do	do	12
do	do	25.00	3.25	do	do	10
Soft; alk	Hand		3.25	Good	Dom; st	39
Hard	do		3.25		do	10
do	Horse		6.00	Good	do	26
Soft				Small	Dom	
Hard	Hand	4.00	3.25	Good	Dom; st	8
Soft	do		4.00	do	Dom	13
Hard	do		5.00	Small	Dom; st	16
Alk	Wind		3.25	Good	do	26
Soft	Hand	40.00	3.00	do	do	8
Hard	Steam	52.00	436.00	323,158 gallons	Irr	34
Soft	do	42.00	436.00	323,158 gallons	do	10
Hard	Hand		3.00	Small	Dom; st	12
Soft	Wind		4.00	Good	do	18
do	do			do	do	12
Soft; alk	Hand		3.50	do	do	10
Soft	do	20.00	4.00	do	do	15
do	do		3.50	do	do	18
Soft	Hand		3.25	Good	Dom; st	8
do	8 wind		35.00	do	do	11
do	Hand	20.00	3.25	do	do	15
Hard	Hand		3.25	Good	Dom; st	20
Soft	Hand	25.00	3.25	Good	Dom; st	12
do	8 wind		45.00	do	do	10
do	Hand		3.00	do	do	20
do	16 wind			do	do	15
do	Wind		70.00	do	do	14
Hard	Hand	57.00	3.25	do	do	28
Soft	Hand		4.00	Good	Dom; st	11
Soft	Hand		3.25	Good	Dom; st	4
Soft	8 wind		49.00	Good	Dom; st	11
Hard	Wind			Good	Dom; st	39
Soft	Hand		3.25	do	do	16
	do		3.00	do	do	14
Hard	do		3.25	do	do	24

[c] Swale water 14 feet below. [d] Swale water 13 feet below.

Wells in Kings River delta—Fresno,

No. of well.	Owner of well.	Location. T.	R.	S.	Year completed.	Class of well.	Depth of well.	Depth to water.	Depth of water.	Strata.
							Feet.	*Feet.*	*Feet.*	
510		16	21	14			(a)	(a)	(a)	
511	J. D. Griffey	16	21	13		B5		12		
512	J. Hamilton	16	21	24	1899	Dr2	22	10	12	SHp
513		16	21	26			(b)	(b)	(b)	
514	Central School	16	21	26		B5		10		
515	Dick Butler	16	21	22	1888	B5	30	11	19	SHpC
516	E. R. Holton	16	21	28	1882	B5	30	7	23	
517	Mrs. M. L. Viere	16	21	15	1882	B5		9		
518	J. F. Crowder	16	21	24	1894	B5	94	10	84	S
519	D. Patton	16	22	9	1880	B5	100	11	89	LS
520	J. B. Fontaine	16	22	4	1896	B5	52	10	42	S
521		16	22	3-10			(c)	(c)	(c)	
522	Percy Fowler	16	22	3	1890	B5		14		
523	Sam. L. Hogue	16	22	12	1885	B5		11		HpCS
524	Prof. Heald	16	23	7	1880	B5		12		SHp
525		16	23	8		B5		12		
526	Prof. Heald and Heley	16	23	6	1897	B5		14		SHp
527	Gust Almgren	15	23	33		B5		33		
528	Gust Stromberg	16	23	4	1899	B6	85	30	45	SHp
529	M. E. Stanton	15	23	32	1888	B5	62	40	22	HpS
530	Jno. Holnberg	15	23	33	1889	B6	93	50	43	HpCSG
531	T. L. Reed	15	23	22	1889	B5		60		LHpCSG
532	do	15	23	27	1889	B6	75	45	30	LHpCS
533	Burris Bros	15	23	26		B5	23	21	2	HpC
534	S. T. Curtes	15	23	35		B5		18		CHp
535	A. Winters	16	23	13	1898	D36	12	6	6	
536	Mrs. A. R. Orr	16	23	12	1890	B5	80	15	65	
537	Mr. Dittman	16	24	7		B		10		
538	J. W. Roberts	16	24	8	1900	B5	70	10	60	CSHp
539		16	24	5		B8	50	8	42	
540	Mrs. A. R. Orr	16	24	4		B		10		
541	K. Gregory	16	24	5	1887	B5	84	12	72	CHpS
542	L. Pederson	15	24	33	1900	B5	75	12	63	CHpS
543	Cal. F. & L. Co	15	24	29		B5	50	13	37	
544	J. S. Jones	15	24	19		B8		17		
545	R. M. Wilson	15	24	19	1891	B7	64	15	49	HpCS
546	J. T. Mance	15	24	18		B5	15	(d)	(d)	
547	Ger. L. & S. Bank	15	23	13	1886	B5	58	22	36	
548	A. L. Holmes	15	23	24		B5	38	29	9	
549	Purington	15	23	24	1890	B5		24		HpS
550	Joe Housley	15	23	27	1890	B6	71	35	36	HpSC
551	J. H. Harden	15	23	15	1885	B6	84	50	34	LHpS
552	P. Legure	15	23	15	1885	B5	85	40	45	HpCS
553	Fink School	15	23	10	1900	B5	100	42	58	HpCS
554	San Francisco Bank	15	23	11		B5		40		CHpS
555	Fisher	15	23	14		B5	80	35	45	
556	Frank South	15	23	14		B5	25	(d)	(d)	
557	F. Fisher	15	23	12		B8				
558	Victor Franzon	15	23	12	1881	B5	60	32	28	HpCS
559	Gosliner Bros	15	24	6		B				
560	do	15	24	7	1885	B7	80	25	55	HpSC
561	Sacramento Bank	15	24	6		B7	30	12	18	
562	Sweets Place	14	24	32		B6		13		CHpS
563	Mr. Martinez	14	24	33	1883	B5	97	12	85	
564	Mrs. Merrit	14	24	29	1885	B6	40	20	20	
565	Alta District	14	24	30		B5	100	20	80	
566	Jake Eppinger	14	23	26	1897	B6	90	27	63	HpCS
567	Mrs. J. D. Reese	14	23	9	1899	D	18	14		G
568	S. W. Lewis	14	22	14	1898	B12	48	18	30	LG
569	N. L. Durgin	14	22	22	1890	Dr2		20		
570	W. H. Spitler	14	22	22		B5	25	16	9	
571	C. Gravani	14	22	17	1898	B2		12		
572	Fruitvale estate	14	19	8	1894	B2	60			
573	I. C. Barman	14	19	18	1893	B1½	85	6	79	
574	Mat. Asmussen	14	18	12	1881	B2	70	8	62	
575	J. C. Appley	14	18	14	1894	B2		8		S
576	John Condon	14	18	26	1894	B2		8		S
577		14	18	26		B2	21	9	12	
578	Geo. P. Thornton	14	19	30	1893	B2	80	8	72	
579	Mrs. G. F. Thornton	14	19	29	1893	B2	90	10	80	HpSC
580	(On county road)	14	19	28		B7		7		
581	Burley Bros. & McNeil.	14	19	22		B2		5		S

[a] Lagoon water 11 feet below.

[b] Swale water 10 feet below.

Tulare, and Kings counties—Continued.

Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Supply.	Use of water.	Salts, parts per 100,000.
Soft	Hand		$3.25	Good	Dom; st	12
do	do	$10.75	3.25	do	do	8
Soft	Hand		3.25	Good	Dom; st	13
	Wind		4.00	do	do	9
Soft	Hand			do	do	8
do	14 wind			do	do	15
do	8 wind		50.00	do	do	14
do	Hand			do	do	8
do	do		3.50	do	do	8
Soft	Hand		4.50	Good	Dom; st	8
do	do		3.50	do	do	17
do	Wind			do	do	24
do	Hand			do	do	17
do	do		12.00	Small	do	14
do	do			Good	do	16
Hard	do	67.00	11.00	do	do	14
Soft	Wind			do	do	12
Hard	Hand		100.00	do	do	15
Soft	do			do	do	12
Hard	Wind			do	do	26
do	Hand		4.25	do	do	12
Soft	do			do	do	11
	Rope			do	do	
Soft	Hand; horse	80.00		do	do	8
do	Hand			do	do	13
Hard	do	36.00	3.50	do	do	14
do	do		5.00	do	do	12
do	do		5.00	do	do	31
Soft	do	40.00	3.50	do	do	13
do	do	30.00	3.50	do	do	12
do	do		3.50	do	Dom	14
do	Wind			do	Dom; st	
do	do			do	do	12
do	Water; hand		6.00	do	do	12
do	12 wind			do	Stock	11
do	Hand		5.00	do	Dom; st	12
do	do			do	do	19
do	Wind			do	do	13
Hard	do	84.00	100.00	do	do	16
do	8 wind	80.00	70.00	do	do	14
do	Hand			do	do	10
do	do			do	do	14
do	14 wind			do	do	10
do	8 wind		47.00	do	do	11
do	Wind			do	Stock	8
do	do			do	Dom; st	12
do	Hand			do	do	10
do	12 wind	80.00		do	do	13
do	Hand		4.00	do	do	13
do	do		5.00	do	do	
Soft	do	97.00	3.25	do	do	13
Hard	8 wind			do	do	17
Soft	Hand		4.25	do	do	8
Hard	Wind			do	do	12
Soft	Hand		12.00	do	do	11
do	Wind			do	do	9
do	8 wind		47.00	do	do	18
do	Hand			do	do	11
	do		3.50	do	do	
Soft	Wind			do	do	8
do	Hand		3.50	do	do	13
Hard; alk	do	21.00	3.25	do	do	
Alk	do			do	do	19
Hard	do		5.00	do	do	20
				do	do	
Soft	Wind	24.00	47.00	do	do	16
do	do	25.00	89.00	do	do	21
Soft	Hand		3.25	Good	Dom; st	32

[a] Swale water 12 feet below.

[d] No water.

Wells in Kings River delta—Fresno,

No. of well.	Owner of well.	Location. T.	R.	S.	Year completed.	Class of well.	Depth of well.	Depth to water.	Depth of water.	Strata.
							Feet.	*Feet.*	*Feet.*	
582	Mr. Harris	13	19	26		B5	17	14	3	
583	Lafayette Pearson	13	19	26	1892	B2		16		HpCS
584	Mr. Williams	13	19	29		B7	35	21	14	
585	S. H. Crane	13	19	30	1888	B7		16		SHp
586		13	18	25	1898	B2		19		
587	Kennedy & Owen	13	18	25		B5	40	16	24	
588	California Bank	13	18	23	1898	B5	100	22	78	
589	Mrs. Thornton	13	19	19	1888	B6	60	20	40	
590		13	19	17		B7				
591		13	19	17		B5				
592	Ed. Ferguson	14	21	12		B2		10		
593	Sierrng Bros	14	21	13	1892	B5	90	10	80	LHpSC
594	P. M. Hart	14	22	19		B2		10		SGS
595	David Antres	14	22	19	1898	B5		10		
596	W. R. Wilson	14	22	21		B5		18		
597		14	22	29			(a)	(a)	(a)	
598		14	22	28			(a)	(a)	13	
599	Will McKenzie	14	22	28		Dr2	54	12	42	
600	Bethel schoolhouse	14	22	34	1888	B5		11		
601	J. A. Roberts	15	22	3	1892	B6	85	14	71	
602	M. A. Colton	14	22	35	1900	B5	58			CS
603	H. O. Marshall	15	22	11		B5		14		
604		15	22	3		Swale		13		
605	A. J. Wells	15	22	9	1883	B5	52	12	40	S
606	H. S. Hulbert	15	22	9	1879	B5	72	10	62	S
607	J. J. Wiley	15	22	15		B5		16		
608	Shafer Bros	15	22	14	1886	B5	70	16	54	S
609	D. C. McClarly	15	22	27	1881	B6	65	15	50	CHpS
610	H. White	14	22	27	1892	Dr2	32	10	22	S
611	G. L. Traber	15	22	26	1877	B5	60	15	45	
612	Mathias Thomson	15	22	35	1892	B5		14		
613	H. F. Graper	16	22	2	1888	B6	48	13	35	CS
614	Helge Lee	16	22	14	1896	B5		13		
615	Frank Hanson	16	22	13	1889	B5	40	15	25	S
616	W. H. Seward	16	22	13	1899	B5	45	15	30	LSHp
617	Charles Strid	16	22	23	1892	B5	30	12	18	GS
618	Wells Anderson	16	22	26	1888	B5	40	20	20	HpCS
619	E. S. Boot	16	23	30	1888	B5	52	25	27	CHpS
620	Mrs. A. Stober	16	23	19	1889	B5	67	17	50	LHpCS
621	A. B. Clark	16	23	19				22		
622	S. F. L. & S. Assn	16	23	18	1886	B5	70	15	55	HpCS
623	N. J. Shadle	16	23	18	1891	B5	60	20	40	HpCS
624	N. J. Layton	16	23	8	1884	B5	64	20	44	HpCS
625	G. Bordson	16	23	6	1888	B5	40	14	26	LHpSC
626	J. A. Beall	15	22	25	1900	B5		17		LHpSCHp
627	J. M. Marshall	15	23	29	1881	B6	116	30	86	HpCS
628	Martin Miller	15	23	30	1880	B5	70	20	50	LHpCS
629	J. A. Milton	15	23	20	1891	B5	68	28	40	LHpS
630	N. Boysen	15	23	20	1891	B8	55	25	30	HpS
631	Milton M. West	15	23	21	1891	B5	45	40	5	S
632	Sacramento Bank	15	23	19	1885	B5	53	30	23	HpS
633	C. O. Love	15	23	18	1885	B6	30	25	5	HpS
634	E. L. Jediker	15	22	13	1884	B5	59	25	34	HpCS
635		15	23	7		B6		45		
636	S. P. R. R. Co	15	23	8		B5		30		
637	Kimble estate	15	23	7		B6	60	35	25	SCHp
638	M. Bassett	18	21	14	1898	B5	44	10	34	SC
639	Aug. Weihe	14	20	5	1897	B2	35	7	28	LHpSC
640	O. J. Ransom	14	20	6		B		9		
641	Geo. Roeding	13	20	31	1900	B5	93	12	81	CHpS
642	Balfour, Guthrie & Co.	13	19	25	1888	B5		24		
643		13	19	35		B8		17		
644	Judson & Stutson	13	19	6	1883	B7	115	60	55	
645	California Bank	13	19	11	1897	B5	83	38	45	LHpSC
646	do	13	19	11	1882	B7	112	38	74	
647	J. E. Rawlins	19	21	1	1882	B6	42	10½	31½	HpS
648	Philips estate	19	22	7	1895	B5	40	10	30	S
649	R. S. Wait	19	21	13	1878	B6	40	10	30	CS
650	C. H. Watson	19	22	19	1893	B5	45	8	37	CHpS
651	Cal. S. & L. Assn	19	21	25	1880	B6	55	9	46	CS
652	A. P. Redding	19	21	36	1889	B10	783	(b)		SCCS
653	A. Onesti	18	21	36		B5		11		
654	A. L. Cressy	18	21	35	1884	B	25	10	15	

[a] Swale water 13 feet below.

Tulare, and Kings counties—Continued.

Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Supply.	Use of water.	Salts, parts per 100,000.
Soft	Hand			Good	Dom; st	
do	do		$3.00	do	do	10
do	Lift			do	do	11
do	Hand		6.00	do	do	14
do	do		3.50	do	do	12
do	do		3.50	do	Stock	17
Hard	8 wind	$100.00	50.00	do	Dom; st	32
Soft	Wind			do	do	12
do	Hand		3.50	do	do	13
do	Wind			do	do	12
do	Hand		3.50	do	do	18
do	Wind	90.00	65.00	do	do	15
do	3 wind		56.00	do	do	14
do	Hand		3.50	do	do	16
do	do		3.25	do	do	19
Soft	Hand		3.00	Small	Dom; st	14
do	Lift			Good	Dom	14
do	Hand		3.00	do	Dom; st	8
do	do	30.00	3.50	do	do	10
do	do		3.50	do	do	12
Hard	Hand	30.00	3.00	Good	Dom; st	14
do	8 wind	79.00	200.00	do	do	11
Soft	Wind			do	do	8
Hard	Hand		3.50	do	Stock	19
Soft	do		3.25	do	Dom; st	8
Hard	do	4.50	3.50	do	do	8
Soft	do		3.50	do	do	13
do	do		3.50	do	do	18
Hard	do	36.00	3.50	do	do	32
Soft	do		3.50	do	do	9
Hard	do	30.00	3.50	do	do	31
	do	35.00	15.00	do	do	33
Hard	do	22.00	3.50	do	do	15
Soft	do	30.00		do	do	12
do	do		11.00	do	do	11
Hard	do	67.00	13.00	do	do	14
Soft	do		9.00	do	do	11
Hard	do	52.00	3.50	do	do	26
do	do	44.00	120.00	do	do	17
	Wind; hand			do	do	21
Soft	12 wind		200.00	do	do	29
do	Wind			do	Dom	15
Hard	12 wind	116.00	42.00	do	Dom; st	11
do	8 wind	70.00	46.00	do	do	13
do	do	48.00	55.00	do	do	17
Soft	Hand			do	do	29
Hard	do			do	do	11
Soft	do	53.00	11.00	do	do	11
do	do		5.00	do	do	11
Hard	Wind	59.00	158.00	do	do	16
do	8 wind		40.00	do	do	12
do	Hand			do	Stock	10
Soft	14 wind			do	Dom; st	8
Hard	Hand	22.00	4.00	do	do	9
Soft	do	8.80	3.50		do	12
do	14 wind; hand			Good	do	8
do	8 wind	73.00	50.00	do	do	12
do	16 wind			do	do	11
do	Hand		6.00	do	do	14
do	Wind			do	do	26
Hard	8 wind	58.00		do	do	38
Soft	do		53.00	do	do	16
do	12 wind	42.00	150.00	do	do	14
Hard	Hand		6.00	do	do	94
Soft	do			do	Dom	40
do	do			do	Dom; st	54
do	do	55.00	7.00	do	Dom	19
Soft; sul		2,600.00		488,920 gallons	Dom; irr	14
Soft	Hand		4.00	Good	Dom; st	12
do	8 wind	25.00	50.00	do	do	16

[a] Flows.

Wells in Kings River delta—Fresno,

No. of well.	Owner of well.	Location.			Year completed.	Class of well.	Depth of well.	Depth to water.	Depth of water.	Strata.
		T.	R.	S.			*Feet.*	*Feet.*	*Feet.*	
655		19	21	11		Dr1½		9		
656		19	21	14		B5		10		
657	Fred Ward	19	21	26		B5		9		
658	Silvan Fereira	19	21	26		B4		9		
659	Jno. Bowers	19	21	36	1894	B9	800	(a)		CS
660	W. S. Burr	20	21	2	1900	B5	44	16	28	CS
661	Mrs. J. Hide	20	21	12		B		15		CS
662	W. V. Walker	18	21	34	1890	B5	35	10	25	
663	Maria Reynolds	18	21	33	1885	B5	36	12	24	CS
664	S. Badger	18	21	32		B5		11		SC
665	Mrs. M. Camp	18	21	30	1880	B5	32	10	22	CS
666	W. J. Weir	18	20	36	1890	B5	40	10	30	SC
667	Mrs. H. Bryant	18	20	36	1880	B5	50	12	38	CS
668	T. L. Hanna	18	20	26	1900	Dr2	42	7	35	CS
669	M. P. Hatch	18	20	27	1882	B5	34	12	22	CSL
670	G. E. Lathan	18	20	33	1897	B5	132	1+	131	CS
671		18	20	33	1900	B5		3¼		CS
672	R. M. Coon	19	20	4	1877	B8	52	8	44	SC
673	James Wright	19	20	10	1892	B6		8		SC
674	J. J. Moss	19	20	10	1888	B6	108	4	104	SC
675	Jno. Hunlen	19	20	16		B7	100+	(a)		SC
676	R. W. Dougherty	19	20	15	1892	B5	139	3¼	135¼	SL. SiltC
677	Mrs. E. Cory	19	20	14	1882	B6	33	8	25	SCS
678	Fred Jennings	19	20	13	1883	B6	36	10	26	CS
679	J. F. Florey	19	20	13	1885	B5	40	8	32	CS
680	G. E. Shore	19	21	18	1889	B7	40	10	30	SC
681	L. R. Love	19	21	20	1890	B5		12		S
682	W. W. Parlin	18	21	15	1880	B5		6		
683	Martin Roberts	19	21	22	1882	B5	25	12	13	SC
684	H. N. Hogle	18	21	25	1880	B4	75	10	65	CS
685	Wm. Hogle	18	21	23	1897	Dr2	100	8	92	CS
686	Mary White	18	21	22	1890	B5	57	8	49	CS.
687	Mike Dutra	18	21	22	1889	B5	50	9		CS.
688	Geo. I. Richie	18	21	21	1895	B5		10		CS.
689	H. E. Ayers	18	21	30	1880	B5		8		CS.
690	Mr. Page	18	20	24	1900	B5	24	8	16	CS
691	J. L. Kurtz	18	20	26	1896	B5	28	7	21	CS
692	J. D. Patterson	18	20	22	1892	B5	106	3	103	CS
693	J. Sutherland	18	20	28	1894	B2	530	(a)		CS.
694	Frank Sharples	18	20	16	1898	B5	170	10	160	SC
695	R. H. Kearns	18	20	27	1894	B2	56	8	48	SC
696	J. Sutherland	18	20	15	1899	B5	96.5	3	93.5	CS.
697		18	20	12		B5		12		
698	T. P. Sutherland	18	20	13		B5		10		
699	W. A. Long	18	21	18		B5	33	6	27	SC
700	C. Lathan	18	21	18	1890	B5	40	6	34	CS
701		18	21	17	1898	B		8		SC
702	Kimball, trustee	18	21	9		B		8		SC
703	Mrs. M. A. Haws	18	21	9	1891	B5	50+	8	42+	SC
704	Jno. Wynrck	19	21	2	1884	B7	608	(a)		SC
705	Mrs. M. Andrews	19	21	10	1882	B5	60	10	50	SC
706	J. R. Mullinix	19	21	14	1880	B6	40	12	28	SC
707	W. S. Slavin	19	21	23	1895	B5	35	12	23	CS
708	Jno. Sigler	19	21	26	1892	B5	65	12	43	SC
709	M. P. Rose	19	21	26	1890	B4		10		
710	A. M. Stone	19	21	34		B5		14		
711	W. Burr	20	21	10		B7		13		
712	C. Paddock	20	21	4		B5	35	13	22	SC
713	M. F. Mines	20	21	4	1891	B5	83	14	69	SC
714	Mussel Slough C. and I. Co.	20	21	5		B5		21		
715	T. J. Smith	19	21	31	1899	B6	38	12	26	CS
716	E. G. Sellers	19	20	36	1895	B5	52	12	40	CS
717	E. Jacobs	20	20	2		B9		(a)		
718	W. Blevins	19	20	26	1892	B6	40	10	30	SC
719	John Hereford	19	20	22	1885	B5	40	11	29	
720	Joe Whiteside	19	20	26	1898	B6	114	8	106	CS
721		19	20	35		D48	10	7	3	CS
722	Judge Shores	19	20	25	1890	B6		10		
723	D. R. Nidiffer	19	21	19	1875	B5	37	10	27	SC
724	H. V. Woodgate	19	21	29		B5		10		
725	Geo. W. Houston	19	21	21	1890	B5	34	12	22	SLSC
726	P. C. Eccles	18	21	35	1891	B4	40	10	30	
727	F. E. Wood	19	21	3	1890	B5	50	8	42	

[a] Flows.

Tulare, and Kings counties—Continued.

Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Supply.	Use of water.	Salts, parts per 100,000.
Soft	Hand			Good	Dom	15
do	do		$3.25	do	Dom; st	15
do	12 turbine		130.00	do	do	31
Alk	Wind			do	do	23
Soft		$1,600.00		do	do	16
Hard	8 wind	22.00	31.50	do	do	92
Soft	Hand		5.00	do	do	12
do	do		3.25	do	do	14
do	do		6.00	do	Dom	9
do	do		3.00	do	do	11
do	8 wind	32.00	53.00	do	do	15
Hard	Hand			Small	do	13
do	do	50.00	4.00	Good	do	17
Soft	do	21.50	4.50	do	Dom; st	8
do	do	20.00	4.00	do	Dom	9
Soft; sul	do	69.00	4.00	do	Dom; st	15
Soft	do		4.00	do	do	23
Hard	Wind				do	24
do	Hand			Good	do	13
Soft	do			do	do	30
Soft; sul				5,789 gallons	Dom	72
Soft	Hand	108.00	4.00	Good	Dom; st	59
do	do	17.00	3.25	do	Dom	14
Alk	do	17.00	4.00	do	do	14
Soft	Wind; hand			do	do	19
Hard	do			do	Dom; st	32
	Force			do	do	10
Hard	Hand		3.00	do	Dom	17
do	do		3.00	do	do	59
do	do	30.00	4.00	do	Dom; st	11
Soft; sul	do	50.00	4.50	do	do	15
Hard		28.50		do	do	9
Soft	Hand		4.00	do	Dom	8
do	do		4.00	do	Dom; st	10
do	do		3.00	do	do	9
do	do		4.00	do	do	37
do	do			do	Dom	13
Soft; sul	do	99.00		do	do	14
do	Artesian			482 gallons	Dom; st	29
do	Hand		4.00	Good	do	13
Soft	do	28.00		do	do	10
Soft; sul	do	65.00	3.00	do	do	12
Soft	do		3.00	do	Dom	8
do	Wind; hand			do	Dom; st	13
Hard	Hand	16.00	4.00	do	do	12
do	12 wind	20.00	65.00	do	do	11
Hard	Hand		3.00	Good	Dom	11
Soft	do			do	do	11
do				do	do	9
Soft; sul		1,333.00		32,166 gallons	Dom; st	21
Soft	Hand		4.00	Small	Irr.; dom	12
do	do	41.00	4.00	Good	Dom	9
Hard	8 wind		4.00	do	Dom; st	75
Soft	Hand	33.00	3.00	do	Dom	13
do	do		4.00	do	do	11
do	do		6.00	do	Dom; st	12
	do		4.00	do	Dom	110
Soft	do		3.50	Small	Dom; st	31
do	do		3.00	Good	do	32
do	(a)					
Hard		18.00	4.00	Good	Dom; st	31
do	Hand		3.50	do	do	33
Sul				6,433 gallons	do	29
Hard	Hand	30.00	3.00	Small	do	22
do	do		3.00	do	Dom	41
Soft; sul		97.00	3.50	Good	Dom; st	37
Hard	Rope			do	do	33
	Hand		4.00	do	Dom	16
Soft	do		3.00	do	Dom; st	12
do	do			do	do	13
Hard	do		4.00	do	do	8
Soft	8 wind			do	do	9
do	Hand			Small	do	13

[a] Alternate layers.

[a] On high ground; 4 feet above average.

Wells in Kings River delta—Fresno,

No. of well.	Owner of well.	Location.			Year completed.	Class of well.	Depth of well.	Depth to water.	Depth of water.	Strata.
		T.	R.	S.			*Feet.*	*Feet.*	*Feet.*	
800[a]	Montgomery Bros	17	22	34	1900	B5	56	13	43	SCG
801	Mr. Jenkins	18	22	4		B5	30	8	22	
802	William A. French	17	22	32	1888	B6	35	8	27	SC
803	M. E. Templeton	18	22	5		B5		8		
804	M. B. V. Garcia	17	22	29	1899	B5		8		
805	Mr. Van Dorset	17	22	29	1900	B5	44	8	36	SC
806	C. W. Clark	17	21	36	1885	B5	60	11	49	SC
807	T. J. Alcorn	17	21	25	1900	B5	42	11	31	SC
808	R. H. G——	18	22	5		B5		9		
809	Frank Griffith	18	22	29	1894	B5	38	12	26	SC
810	Joe Rogers	18	22	28		B5		11		
811	S. B. Hicks	18	22	33	1880	B5		9		
812	Perry C. Phillips	18	22	35		B5		9		
813	do	18	22	25	1900	B5	138	12	126	SC
814	do	18	22	36		B5		16		
815	J. H. Murray	19	22	12	1892	B5	43	14	29	CS
816	W. Hampshire	19	22	11	1900	B5	30	8	22	LQsCS
817	R. Abbot	19	22	3	1899	B4	100	9	91	CS
818	P. Sweeney	19	22	14	1878	B5	40	8	32	SCSC
819[a]	Mrs. M. J. Covert	19	22	22	1878	B5	40	14	26	S
820	G. L. Fletcher	19	22	15	1889	B5	56	10	46	
821	Cal. S. and L. Soc	19	22	9	1880	B4	+22	10	+12	
822	Harry Peacock	19	22	3	1873	B5	75	9	66	
823	E. Pichett	18	22	35	1885	B5		9		
824	F. M. Hart	19	22	4		B5		9		
825	Cross Creek schoolhouse.	18	22	32		B5		9		
826	C. Waldorf	19	22	5		B4		8		
827	Fred Dunn	19	22	7		B5		12		
828	M. Braverman	19	22	9		B5		9		
829	Evelyn Davis	19	22	17		B5		9		
830	Robt. Dougherty	19	22	21		B5	15	8	7	
831	Eucalyptus schoolhouse.	19	22	21		B2		8		
832	S. L. Worley	19	22	28	1880	B5	30	13	17	
833	Robt. Dougherty	19	22	23		B5	30	14	16	SC
834	T. McCarthy	19	22	34	1876	B5	75	13	62	
835	Mrs. J. T. Hereford	19	22	34	1875	B6	40	11	29	
836	H. M. Richardson	19	22	34	1875	B5	30	10	20	
837	E. McCarthy	20	22	3		B5	64	14	50	
838	Wm. Rourke	20	22	3	1888	B5	30	17	13	SC
839	W. H. Heldebrand	20	22	10	1880	B5	34	16	18	
840	J. M. Moore	20	22	10	1900	B7		15		
841	Lakeside School	20	22	5		B5		14		
842	P. McCarthy	20	22	8	1886	B9	600	(b)		CS
843	F. E. Howe	20	22	8	1891	B8	750	(b)		
844	Lakeside Creamery Co.	19	22	33	1890	B5	60	15	45	SC
845	Geo. Clute	19	22	31	1885	B10	900	(b)		CS
846	J. H. Deardoeff	19	22	8		B5		10		
847	Susan Hill	19	22	20	1899	B5	30	10	20	
848	S. A. Brewer	19	22	20	1891	B5	54	12	42	SC
849	Sacramento Bank	19	22	20		B5		12		
850	A. & J. Toomey	19	22	32		B6		(b)		
851	Wm. Northup	19	22	31	1898	B5	30	12	18	CS
852	Mrs. C. Brown	18	22	15	1880	B5		12		
853	C. A. Roberts	18	22	16	1891	Dr1½		8		
854	E. Jacobs	18	22	17		B5		11		

[a] On higher ground.

[b] Flows.

Tulare, and Kings counties—Continued.

Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Supply.	Use of water.	Salts, parts per 100,000.
Soft	Hand	$28.00	$3.50	Good	Dom	10
do	do		3.00	do	Dom; st	8
Hard	do	17.00	3.50	do	do	13
Soft	8 wind		50.00	do	do	11
do	12 wind; hand			do	do	9
Hard	Hand	22.00	4.00	do	Dom	8
Soft	do	60.00	4.00	do	do	10
do	do	14.00	5.00	do	Dom; st	11
do	do			do	do	52
do	do	27.00		do	Dom	13
do	do		3.00	do	do	21
do	do		2.25	do	do	12
Hard	do		5.00	do	Dom; st	31
Soft	do			Small	Dom	50
do	do		4.00	Good	do	16
do	do	40.00	3.25	do	Dom; st	11
do	do	22.00	3.25	do	Dom	8
Hard	do	50.00	3.00	do	Dom; st	39
Soft	do	40.00	2.25	do	do	10
do	Hand; wind		3.25	do	do	10
do	Hand	56.00		Small	do	12
Hard	do		5.00	Good	do	48
Soft	14 wind; hand			do	Dom	16
	Hand		3.00	do	Dom; st	28
Hard; alk	8 wind		3.50	do	do	8
Soft	Hand		3.50	do	do	12
do	do		6.00	do	do	20
do	do		3.50	do	do	16
Hard; alk	do			do	do	46
Soft; alk	8 wind		41.00	do	do	128
Soft	Hand		5.00	Small	do	226
do	do		2.25	Good	Dom	9
Hard; alk	do		3.50	do	Dom; st	18
Hard				do	do	14
Soft	Hand		3.50	do	do	12
do	do	40.00	6.00	do	Dom	8
Hard	do		20.00	do	Dom; st	14
Soft	do	64.00	2.75	do	do	17
do	do	30.00	4.75	do	do	9
do	8 wind	34.00	114.00	do	do	12
Alk	do		50.00	do	Stock	
Soft	Hand		3.50	do	Dom	11
Soft; sul		1,500.00			Dom; st; irr	13
do		1,250.00			do	12
Soft	Hand	45.00	12.00	Good	Dom	15
Soft; sul	Artesian	1,900.00			Dom; st; irr	15
Soft	Hand		2.25	Good	Dom	27
do	8 wind		35.00	do	Stock	17
do	Hand	30.00	2.50	do	Dom; st	29
do	14 wind; hand			do	do	18
Soft; sul					Stock	13
Soft	Hand	22.00	3.00	Good	Dom; st	19
Hard; alk	do		3.00	do	do	12
do	do			do	Dom	11
Soft	do		3.00	do	Dom; st	11

In 1882 Mr. C. E. Grunsky, then an assistant in the California State engineering department, made a careful study of the Kings River water supply. In 1898 he made a further study of the district for the hydrographic division of the United States Geological Survey, the results of which are published as Water-Supply and Irrigation Paper No. 18, which has previously been referred to and from which the following extracts regarding the ground water are made:

In no other irrigated region in California is the effect of irrigation on the elevation of the water table so plainly apparent as in the vicinity of Fresno. Here, notwithstanding the 6 feet per mile slope of the surface of the country, the subsoils have been and are being gradually saturated with water. When irrigation commenced the loss of water from canals in transit to lands to be irrigated was very great, and after reaching its destination it was found that frequently enough water was put upon the surface of individual small tracts of land to have covered them to an average depth of 15 to 20 feet in a season. Most of this water found its way into subsoils, together with the direct loss of water from the canals. When the first wells were dug at Centerville water was found at about 20 feet. It is now at 10 to 15 feet below the surface, and will probably not rise much higher on account of ample drainage of subsoils and a comparatively free subsurface flow toward the low river bottoms. [The same in 1900.]

Along Fancher Creek, where the creek is used as a canal, ground water was formerly at 50 to 75 feet below the surface; it is now at 12 to 20 feet along the upper portion of the creek, and still nearer the surface near the former sink of the creek, about 4 miles east of Fresno. In the Eisen vineyard, 5 miles east of Fresno, ground water is at 4 to 6 feet below the surface, and drain ditches have been constructed to prevent a further rise. Ground water is found at 4 feet below the surface in many parts of Temperance Colony, Nevada Colony, and Fresno and Central colonies. Throughout a considerable area near Fresno its surface is nowhere more than 16 feet below ground, though before irrigation commenced depth to water was 60 feet. Cellars which were in use until 1884 in Fresno have been condemned because ground water made its appearance in them. Near Selma and Kingsburg ground water was formerly found at about 30 feet. It is now at about 15 feet. [It was at 12 feet in 1900.] The so-called "Sand Hollow," which is a depression 100 yards to one-fourth of a mile wide, 12 miles long, and about 16 feet deep, having a southerly course, and passing about midway between Selma and Kingsburg, was formerly as dry as the surrounding plain. About 1880 the soil in its bed was found to require less moisture to produce crops than the adjacent plain; in 1885 water appeared at the lowest points of the bed, and in June of that year it had risen to the heads of ripening grain. Spots of black alkali now mar its bed and sides, which before were a light sand, apparently free from any excess of alkaline salts.

Near Sanders and at points eastward from there toward Kings River ground water was at 50 to 60 feet before irrigation commenced; it is now at 20 to 30 feet. Here, as in the case of Centerville, proximity to the river, which lies 60 feet below the surface of the plain, may interfere with a much greater rise of the ground-water plane.

In connection with this change in the elevation of the ground-water plane, it must be remembered that the effect of irrigation extends far beyond the points now under ditch. Owing to the slope of its surface and consequent hydrostatic pressure, ground water has a slow but certain motion westward through pervious subsoils of the Fresno region, and may therefore ultimately contribute more or less toward the flow of Fresno Slough and San Joaquin River.

At the time irrigation commenced near Fresno the soils and subsoils were dry; depth to ground water was 30 to 60 feet. The ground was porous, generally sandy, sometimes very hard on the surface. When wet it was converted into a bog.

Water passed through it readily into the lower strata. Thorough wetting compacted the soil and it was less liable to conversion into slush after the first and second wettings than before. It settled, as a result of the first wetting, about 8 inches to 1 foot, on an average. Sometimes the full supply of a ditch would flow for hours into a hole formed by the breaking in of the surface. Cavities 20 feet in diameter and 6 to 10 feet deep were occasionally formed in this way, and had to be refilled after the first wetting. The stability of buildings was in danger when water was first brought near them. It is not surprising, under these circumstances, that when irrigation commenced in this region sometimes enough water was run on small areas at one irrigation to have covered them 5 feet in depth, and that enough water was delivered to some of the 20-acre colony lots south of Fresno to have covered them to an average depth of 20 feet. After irrigation was practiced for a time the soils became more compact, absorbed water less rapidly, and a smaller amount of water passed into subsoils. At present the ground water near Fresno is so near the surface that the roots of alfalfa, vines, and trees readily penetrate to it and soils are kept moist by the water rising from below. Surface wetting has become unnecessary in many sections.

By the rising of the ground water plane near Fresno large tracts of land have been permanently moistened. Some are very thoroughly subirrigated, and in many instances injuriously so. Relief must be sought in some localities either by drainage or by proper regulation of the supply of water to the district whereby the elevation of the water table may be controlled.

Without attempting to express in detail the acreage irrigated per cubic foot per second of canal capacity or actual flow of water, it may be noted that the total volume of water brought to the vicinity of Fresno during the seventeen years 1879 to 1896 would at a very low estimate have covered to an average depth of about 0.8 foot per annum the entire 260,000 acres of the region through which the canals send their branches. It would have covered the 50,000 acres to whose surface water is actually applied to an average depth of 4½ feet per annum, or to a total depth of 75 feet. Some of this water has of course been consumed in sustaining plant life, more has been evaporated, but the most of it still permeates the subsoils of the irrigated region and of the lands to the west.

Pl. XXVI shows the regimen of the water plane near Hanford as determined by Mr. Grunsky.

A study has been made of the amount of water that has been used for irrigation on the Kings River delta during the last five years. It has been assumed that 4,000 second-feet of water (the aggregate discharge of the canals), when available from the river, were diverted between March and October, inclusive, and that during the remaining four winter months 2,000 second-feet, when available from the river, were diverted for irrigation. From the tables of daily flow the following results were obtained, on the foregoing basis:

Estimated seasonal diversion for irrigation from and seasonal flow of Kings River.

Season November 1 to October 31.	Seasonal irrigation diversion.	Total flow.
	Acre-feet.	*Acre-feet.*
1895-96	1,070,900	1,852,425
1896-97	1,198,691	2,088,924
1897-98	820,522	876,079
1898-99	996,307	1,227,217
1899-1900	1,032,158	1,281,051
Five-year mean	1,023,716	1,465,139

Probably one-fourth of the amount diverted is lost by seepage from the main canals and their laterals. Prof. L. G. Carpenter, of the Colorado Agricultural College, found that on Cache la Poudre River 30 per cent of the water that was applied for irrigation returned to the river below by seepage. Still larger percentages have been found in Utah, and the writer personally knows that similar conditions exist on Gila and Salt rivers in Arizona. If one-third of the remaining water applied on the fields for irrigation sinks to the water plane, we have a total seepage volume from losses in transit and from irrigation of 511,858 acre-feet annually. This great volume of ground water undoubtedly has a slow westerly movement in harmony with the surface slopes. This is indicated by the fact that there is a marked annual fluctuation in the elevation of the water plane, it being from 2 to 4 feet higher about July 1, after the heavy spring irrigation, than in October, at the end of the season's drought. If a pumping system were put in to draw upon this water plane for irrigation purposes, a portion of the water pumped would be lost by evaporation, but probably one-third would return to the water plane. Thus if 300,000 acre-feet of water were pumped the permanent withdrawal would be not more than 200,000 acre-feet, and the annual supply would be from two to three times that amount.

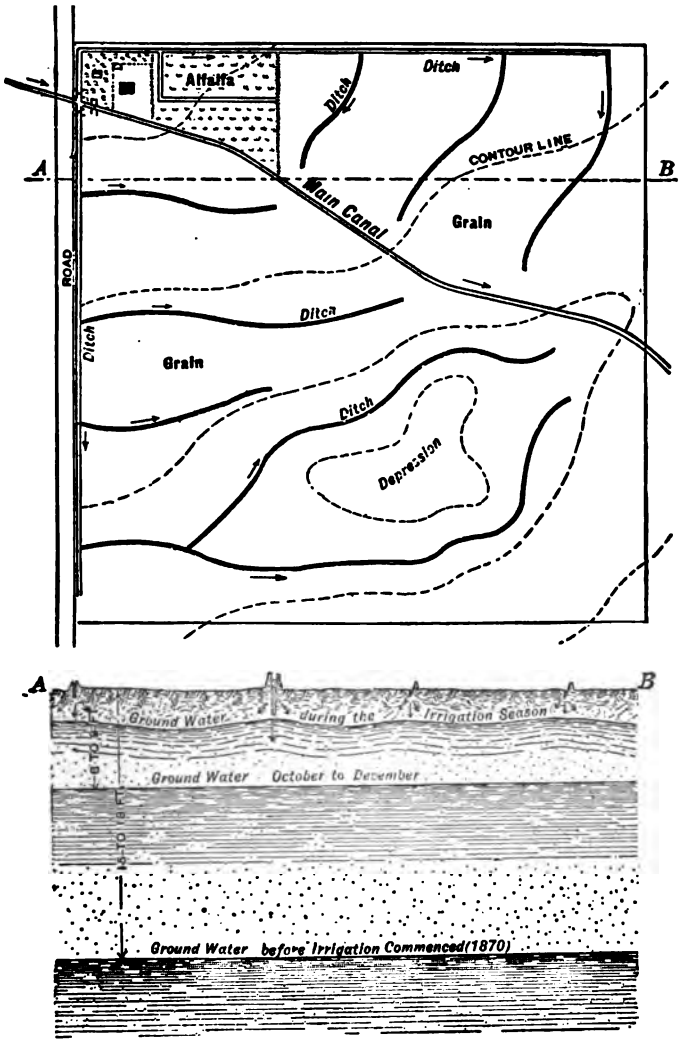
From the foregoing facts it is believed that a supply as great as 300,000 acre-feet can be obtained with certainty by pumping from the water plane of the Kings River delta.

The annual replenishment of the ground water is briefly discussed (pp. 87 to 88) in the accompanying report of Mr. Lewis A. Hicks on the generation and transmission of electric power and the installation of pumping plants.

As there is a heavy loss in the diversion canals, as this loss increases with their length, and as the general movement of the ground water is with the slope of the country in a southwesterly direction, it is believed that the best location for the pumping plants is near the lower ends of the canal lines and at the westerly portion of the irrigated lands. If located there a portion of the loss from the canals would be obviated, owing to their shorter length, and at the same time the pumping plants would have an ample water supply and the lift for the pumps would be slightly less. If the pumping plants were located near the upper end or the center of the canal lines they would probably draw directly from the canals water which otherwise would flow to its destination by gravity.

ALKALINE CONDITIONS.

The water of Kings River is almost chemically pure. Its alkalinity is negligible. The alkali encountered in the valley comes from the soil, largely from a calcareous hardpan which is found in some localities. In rising the water plane reaches the point where capillary action



PLAN AND GEOLOGIC SECTION SHOWING EFFECT OF IRRIGATION ON WATER PLANE IN THE HANFORD AREA OF THE MUSSEL SLOUGH COUNTRY, CALIFORNIA.

continually draws water from below and evaporating leaves practically all of the dissolved salt on the surface of the ground. Anything that will lower the water plane will tend to the reduction of surface alkali. If the voids in the soil be taken as one-third of the mass and 200,000 acre-feet of water are removed each year, then 600,000 acre-feet of soil are drained, equivalent to a depth of 2 feet over the entire irrigated area. It has previously been shown that this amount will be resupplied from the river. Nevertheless the tendency of the pumping plants would be to prevent the water-logging of the land and its alkalinity. As the amount of pure river water that is added to the water plane each year is greater than the amount of water that would be pumped and partially evaporated, the tendency would be to continually dilute the salt in the ground water. It is believed that the alkali is caused by the rising water plane, and it is likely that one of the principal provinces of the pump in the future will be to fight alkali by keeping down the water plane.

Mr. Thomas Means, of the Division of Soils of the United States Department of Agriculture, has personally made a study of alkaline conditions of the soil and water of the Kings River delta. He has devoted a great deal of time and thought to the general study of the alkali problem, and his views are very valuable in considering this subject. He has kindly furnished the following for use in this report:

The salt content of the waters near Fresno has been plotted. No marked lines of zones of underflow were found. The wells with the greatest amount of solids seem, however, to be in the alkali area and along the lower part of the valley. The wells in the portion of the valley north of Fresno are generally of lower salt content than the wells south of Fresno, yet an occasional well with a salt content as high as from 15 to 20 parts is found.

The water table under the Fresno Plains before irrigation was commenced averaged from 30 to 120 feet below the surface. At present the average depth to standing water in the Fresno area is about 10 feet, and during part of the year the level rises about 3 feet. Much of the area south and east from Fresno has the water table at about 6 feet, and during part of the year this level rises to within 2 or 3 feet of the surface. The Hanford area of Mussel Slough country has the level of standing water about 8 feet below the surface of the ground. [See Pl. XXVI.] During the winter the level of this standing water rises about 4 to 6 feet, so that over a great deal of the country the water table is within from 2 to 4 feet of the surface. Here the salt content of the water is greater than around Fresno, averaging about 20 parts per 100,000, while a few wells contain over 100 parts per 100,000.

The salt content of the water of Kings River is about 8 parts per 100,000, the most of which is lime carbonate. The scheme proposed for the irrigation of the desert lands of the area with the water pumped from below the land seems perfectly feasible to me and should, from the way I reason, lessen instead of increase the trouble with alkali. There is but one source of addition of alkali to the country, that is, the water which is taken out of Kings River for irrigation. This water is so pure and the salts which it does contain being lime salts are a benefit rather than a detriment to plant growth. For all practical purposes the only alkali with which we have to deal is the alkali which is at present in the soil.

Alkali salts to be harmful to vegetation must be concentrated within the top 2 feet of soil. Buried below this depth, or if evenly distributed through the soil in

quantities not greater than 0.4 per cent of the dry weight of the soil, no trouble is ever experienced in raising ordinary farm crops (except in the case of the carbonate of soda or black alkali, which is harmful if present in quantities greater than 0.1 per cent). If the alkali be allowed to accumulate near the surface of the ground the roots of the plants are unable to perform their proper functions and the plant suffers, fails to ripen the fruit or dies.

There is a difference in the rate of upward and downward movement of the alkali salts. Experience has shown that the alkali salts move upward more readily than the same salts can be carried downward. This is because the upward movements are entirely capillary and the film around the soil moves, while the downward movement is largely gravitational and through the larger pores so that the film movement is small. This explains the reason why it is that even after large quantities of water are applied to a field of alkali salts may yet come to the surface.

Since alkali rises mainly by virtue of the capillary movements of the soil moisture, the capillary powers of the soil and the depth to standing water are the controlling factors of the rise of alkali. By the capillary power is meant the rapidity with which the moisture will rise within the soil. A heavy clay soil will raise water by capillarity much higher than a sand or silt soil, but the rate with which the water is raised is so slow that the soil is said to be of low capillary powers. In the same way a sandy soil, although the capillary rise is rapid, the height to which the water rises is not great, and the soils are said to be of low capillary powers. Silt soils, soils composed of very fine sand, and loam soils with a medium percentage of clay are generally classed as soils of great capillary power. The alkali soils of the San Joaquin Valley are almost without exception soils of great capillary power. Other soils of the same area which had all the conditions necessary for the accumulation of the alkali salts at the surface, except the fact that the soils were of low capillary power, are to-day free from accumulation of alkali. The Fresno sandy loam, or white ash land as it is locally known, is of great and rapid capillary power. The greater part of the land has been injured by the alkali which it contained. On the other hand the Fresno white sand, which is found typically developed on the plains around Caruthers and which is of low capillary power, although it originally contained within 10 feet of the surface as much alkali as did the white ash land, is very seldom found troubled with alkali.

The second factor in the accumulation of alkali is the depth to standing water. So long as the level of water does not come closer than 4 or 5 feet from the surface of the ground, practically none of the soils will become alkaline if cultivated. The reason for the accumulation of the alkali in the colony lands south of Fresno is that during part of the year the level of standing water comes so close to the surface as to permit continual upward movement and therefore rapid accumulation of the salts. White ash lands around Selma are found very fertile and give large returns where cultivated in fruit, yet an examination of these lands has shown that they contain within 10 feet of the surface as much alkali as do some of the alkali soils south of Fresno. The difference is this: the level of standing water at Selma never comes close enough to the surface (never closer than 6 feet) to permit rapid upward movement of the water. The consequence is that the salts either remain in the deeper subsoil or are distributed throughout the 10 feet. If ever the level of standing water around Selma is allowed to raise to within 3 or 4 feet of the surface, large areas of now fertile land will be rendered barren.

In this respect the scheme proposed for pumping promises to be of great assistance in the prevention of the further extension of the area of alkali land, but it promises also to be of great assistance in the reclamation of the lands already damaged. The pumps will be most active at the time the water table is ordinarily highest, and the amount of water taken from the soil will probably either prevent this rise or lessen its height. There is no question that if this annual rise of

the water table could be prevented and the level of the water kept at its lower position the reclamation of all but the lowest of the alkali lands would be possible without a great and expensive system of drains.

Now the question is: Would the continued use of the water which lies below the land so concentrate the salt that it would in time contain too much salt for plant growth? My opinion is that it would not. You would be continually drawing the water from the depth of say 50 feet and applying the water to the surface of the ground. Part of this water would be evaporated, part used by the plant, and part would drain away to the rivers. The remainder would remain in the ground, but it would be continually diluted with the water which escapes from the irrigation canals and from irrigation and which now causes the annual rise of the water table. The absolute amount of alkali would diminish instead of increase, for the plants would take up some of the salts and another part would drain away into the country drainage. The concentration of the water would probably increase, but, as I have said before, I think the dilution of the irrigation water taken from the river would prevent this. If the water is drawn from a depth of 50 feet there are 15 feet in depth of water to be pumped before the same water is used the second time. Under ordinary pumping irrigation ten years would be required to effect this, and during these ten years sufficient water would have filtered in from the gravity irrigation around and above to dilute this salt. Moreover, at seasons of very high flood the soils could be irrigated with flood water at a slight expense, since the greater part of the country has been ditched.

Most of this applies directly to the Fresno country. Around Hanford the conditions would be slightly different, for here the rise in water table takes place in the winter; yet I can not see where this will affect the problem.

To sum the matter up, I think the result of pumping, if the pumping be carried on only to such an extent as to move the water which is now lost by seepage, would be to improve the conditions rather than to increase the trouble from alkali. The water table would be lowered sufficiently to permit the washing down of the alkali salts, and the salts, instead of being confined to the surface layers of the soil, would gradually be distributed throughout the 50 feet of soil, and by this dilution rendered harmless. The lowering of the water table would be of the greatest assistance to the reclamation of the lands already alkaline, and would probably permit this reclamation without extensive under-drains.

GENERATION AND TRANSMISSION OF ELECTRIC POWER AND INSTALLATION OF PUMPING PLANTS.[a]

INTRODUCTION.

The generation of power from the waterfalls of the high sierras flanking the wide expanse of unused yet fertile lands which form so large a part of the broad San Joaquin Valley, and its utilization, through electric transmission, for pumping the irrigating water supply in the valley, is a subject which fascinates the physicist as an example, on a large scale, of the conservation of energy, and it does not lose in attractiveness when considered as an engineering possibility quite within the range of known experimental results and susceptible of exact statement as to the cost of developing and producing continuously a unit quantity of water.

Several years ago the writer pointed out that the high load factor (the ratio of the average to the maximum load) which could be realized in the operation of a power plant handling a purely pumping load would reduce the cost of pumping sufficiently to make this method of water development economically possible, and as the result of the present investigation it is apparent that the required investment per acre-foot produced compares favorably with the cheapest surface-catchment projects, and that the annual cost of operating would be less than by any other method of extending the water supply, provided it is deemed advisable to operate the plant continuously throughout six or more months of the year. The very complete physical data which are available from the surveys, stream measurements, and photographs taken have made it possible to study the problem in detail. It falls naturally into three subdivisions: (1) The possibility of power development on Kings River depending on the fall and minimum run-off available within reasonable limits of conduit length; (2) the cost of generation, transmission, and application of sufficient power to pump 1,000 acre-feet of water daily for the irrigation of lands between Fresno and Hanford; and (3) the possibility of developing that amount of water continuously from the gravel storage of the alluvial cone of Kings River.

POWER AVAILABLE.

The site selected for the power house is at the junction of the South and Middle forks of Kings River, at an altitude of 1,980 feet. The diversion planned is from the Middle Fork, through 14,000 feet of continuous tunnel, with working adits at frequent intervals, delivering a maximum flow of 180 second-feet at the penstock, which is 680 feet above the water wheels.

[a] Report of Lewis A. Hicks.

The watershed tributary to this diversion contains an area of 325 square miles and rises to an altitude of 14,000 feet. The least mean monthly run-off during the last five years, which were years of drought, occurred in September, 1898, when the Red Mountain gaging records indicate an available mean flowage at the Middle Fork diversion of 85 second-feet. Following is the mean monthly minimum flow during these five years:

Mean monthly minimum flow of the Middle Fork of Kings River.

September—	Second-feet.
1896	206
1897	138
1898	85
1899	90
1900	126

In each year the minimum month was September. During the rest of the year the available flow was never less than 100 cubic feet per second, a quantity sufficient to generate the full load output contemplated. The recurrence of extremely dry seasons at more frequent intervals than ten or fifteen years is not probable and does not properly constitute a limitation of the plant to be installed.

ANNUAL REPLENISHMENT OF GROUND WATER.

A study of the water supply available for pumping, which has been fully considered by Mr. Lippincott, shows it to be ample to furnish the maximum of 328,500 acre-feet required annually by the pumping plants, and the supply will probably be much in excess of the demand.

Experience in Kern County, on a scale relatively as great, shows that the water plane is maintained, notwithstanding continuous pumping, where the wells are in proximity to gravity canals, and that while the plane of saturation is lowered during seasons when the canals are deprived of water it soon regains its former level when the use of the canals is resumed.

A careful study has been made of the data acquired by the extensive observations of the existing water plane in the Kings River delta, as revealed by more than 800 wells, supplemented by information given by well borers familiar with the district. The average wells for irrigating purposes have a log similar to the following:

Representative log of wells in Kings River delta.

	Feet.
Soil	7
Hardpan or clay	2 to 8
Coarse sand	10 to 50
Heavy clay	30 to 60
Coarse sand	4 to 6

The first layer of sand is generally found to be alkaline and is cased out, dependence being placed on the second stratum of sand, from

which the supply is drawn through the open bottom of the casing. Under pumping such wells at first discharge considerable sand, creating around the casing a cavity of such dimensions that the entering velocity of the water is reduced to a point where its transporting power is lost. Where the clay roof is sufficiently thick to prevent caving these cavities may become very large and the capacity of the wells be proportionately increased. A formation of this character is therefore exceptionally favorable to the development of large quantities of water.

The storage capacity of the area affected by the annual infiltration above the level to which the water plane might be reduced by continuous pumping is not less than 2,000,000 acre-feet.

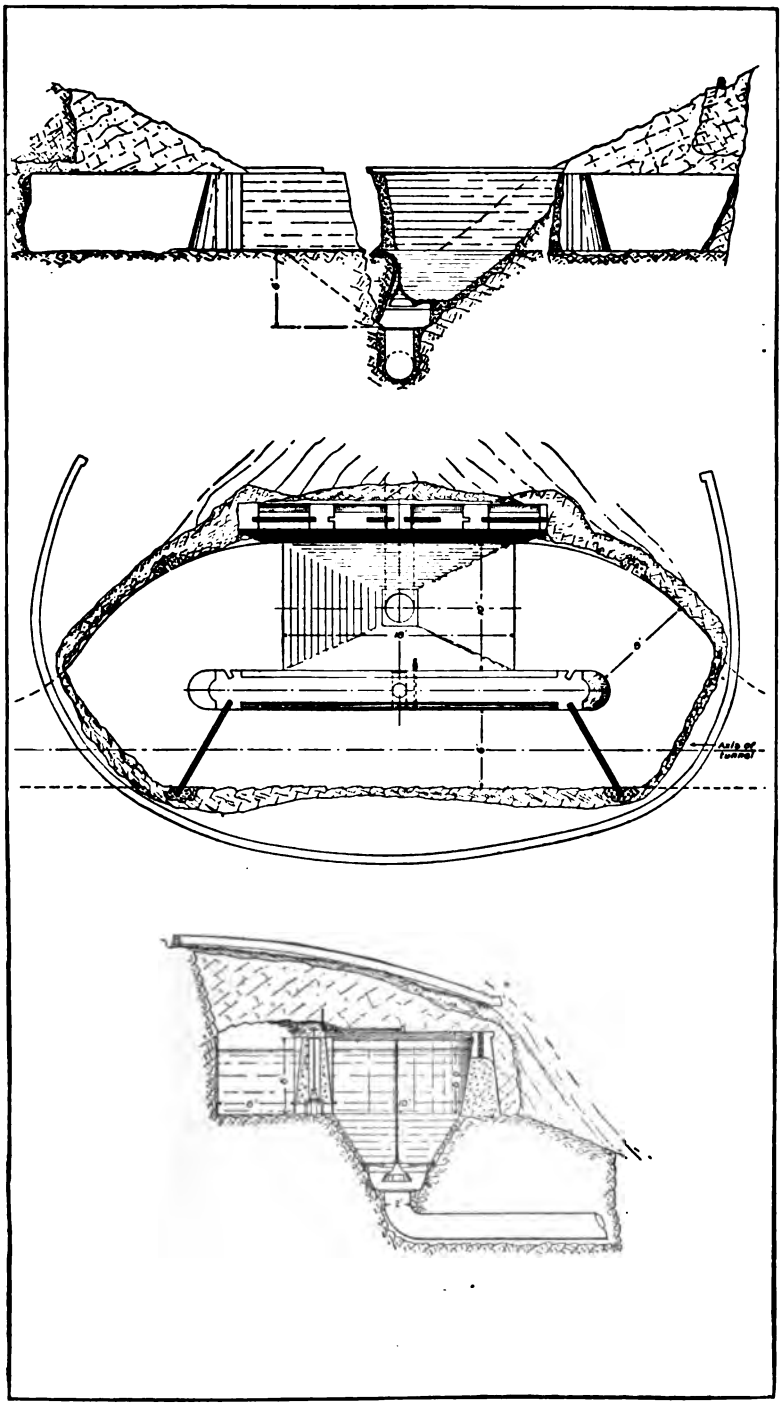
In the light of experience and of the data presented regarding storage capacity, rate of replenishment, favorable formations encountered, and the reabsorption of a part of the water pumped, the writer believes it entirely conservative to say that the quantity of water estimated upon in this report can be continuously developed from the gravel beds of the Kings River delta by the methods outlined.

PLANT PROPOSED.

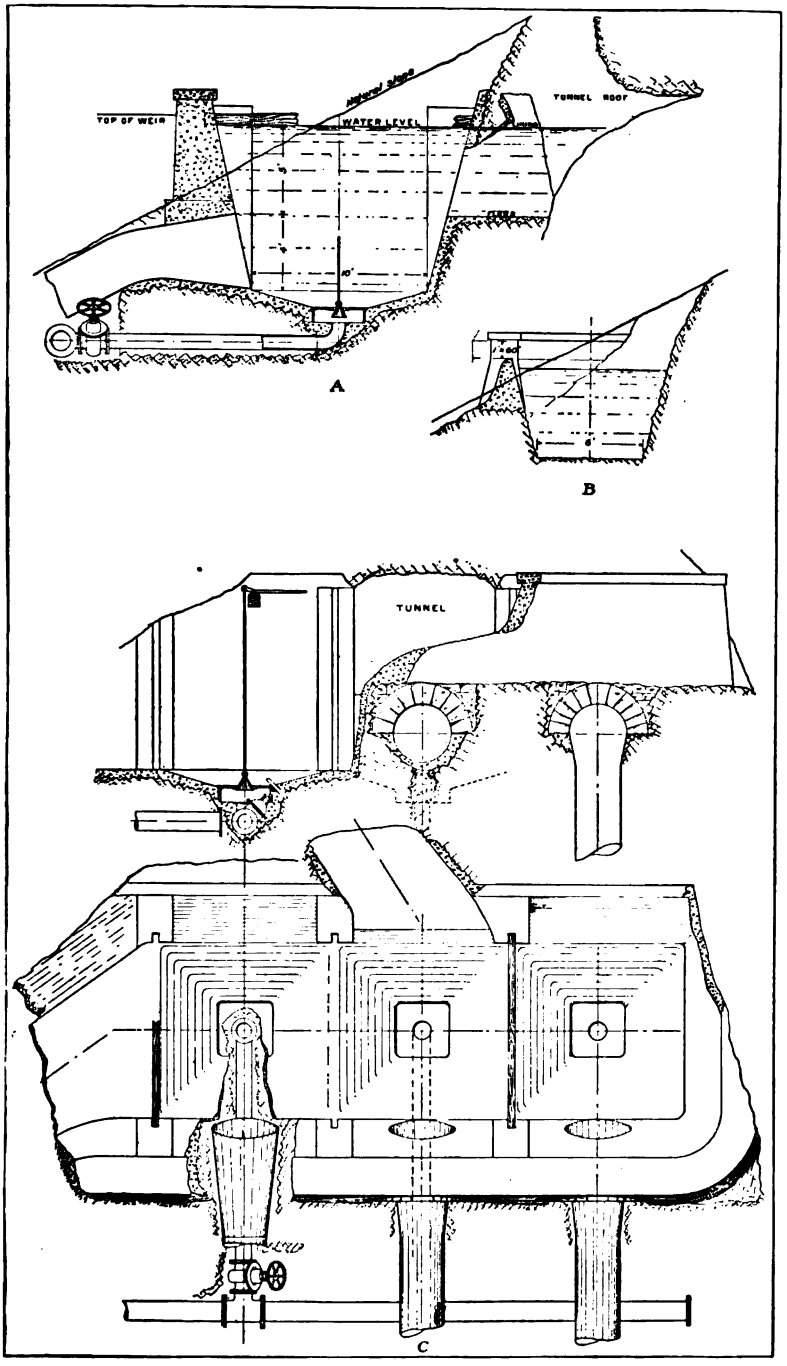
While the limits of this report make it necessary to omit many of the details, the general characteristics of the designs will be stated briefly before summarizing the estimates. The figures used for cost of intake, conduit, roads, bridges, and trails were prepared from preliminary surveys, and appear to the writer to be amply large to cover any probable modification of design or location. A description of the rest of the plant follows in order, from the intake to the pumps.

SAND TRAPS.

Ordinarily the water is very clear and carries but little silt. Provision has been made, however, for trapping the granitic sand which is present in all streams of the upper sierras during the spring freshets, while the snow is melting. The saving effected in the erosion of wheel buckets and nozzles justifies this expense. The normal conduit velocity through the traps for full-load conditions has been reduced to a little more than 1 foot per second, and at the penstock the transverse velocity will be less than 0.5 foot per second. This has been cheaply effected by locating the structure in one of the small lateral drainage lines intersected by the tunnel alignment at grade, and diverting the drainage around the open cut by means of a small training wall. Movable flashboard will make it possible to flush the settling chamber withou interferi wit' the continuous flow of the conduit, and a by-pass wi equaliz the pressure on the flashboards. Flushing may be continuous when water is plentiful, and be intermittent or cease entirely when the flowage is less than required. A waste weir is provided for regulation and for use when



LONGITUDINAL SECTION, PLAN, AND TRANSVERSE SECTION OF SAND TRAP.



DETAILS OF PROPOSED POWER PLANT.

A, Section of tunnel; *B*, section of wasteway; *C*, plan of penstock.

it is desirable to shut off entirely the flow from the penstock. Pl. XXVII shows a longitudinal section, plan, and transverse section of the sand trap.

PENSTOCK.

As designed, this structure is divided into three bays, from each of which a pressure pipe is taken out. The bays can be separated by flashboards placed in grooves in vertical buttresses, and the pressure pipes can be shut off by stop boards between the buttresses. The tunnel enters the penstock in the center bay. The surface elevation of the water in the penstock can be regulated by stop boards between the portal buttresses. An overflow weir is provided to carry the maximum flow of the conduit when all outlets below are closed. Sections of the tunnel and wasteway and plan of the penstock are shown in Pl. XXVIII.

PRESSURE PIPES.

The three pipe lines are designed to be 30 inches in diameter, of steel plates riveted in place, with full-load velocities of 7 feet per second and an effective head of 660 feet, requiring a flow of 100 cubic feet per second to generate the rated output of the dynamos. Each pipe is equipped at frequent intervals with air valves of large area. The pipes are to be placed in a trench to a depth of half their diameter, anchored to rock in situ, and covered with rough rubble. A concrete thrust block is provided at the foot of each pipe, which tapers from a diameter of 30 inches at the thrust block to 18 inches at the gate valve (18-inch) in the power house immediately back of the nozzles. Each pipe feeds to a single generating unit, with practically no curvature in reaching the wheels. In case it is necessary, however, to feed two units from any one of the three pipe lines, this can be accomplished through a 30-inch by-pass connecting the three pipes back of the thrust blocks and not shown in the drawings.

POWER HOUSE.

In designing such a structure the endeavor should be to obtain, as cheaply as possible consistent with long life and utility, a safe and convenient assemblage of the necessary apparatus in such a manner that all working parts of the plant shall be easily accessible for repairs and that possible future extensions can be made in conformity to the same general plan, also to concentrate the machinery, so far as is consistent with safety, in order to minimize the expense of attendance. This has been the aim in planning these works.

The power house, as designed, is shown in plan, side elevation, end elevation, and transverse section in Pl. XXIX. It is believed that the intense summer heat justifies the substantial character of the design and that the use of the granite country rock will be cheaper than any alternative material offering results equally satis-

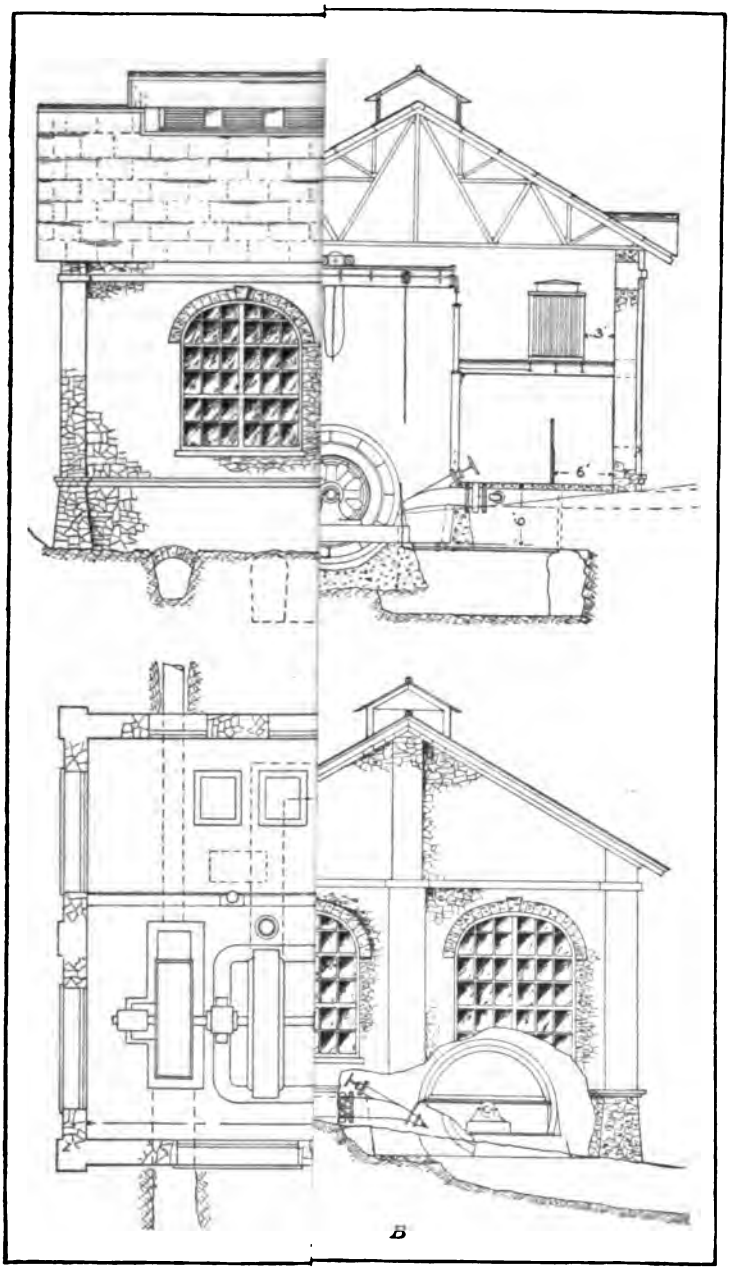
factory. Thorough ventilation will be obtained through louver openings in the roof ridge and by exhaust fans connected with the cool air in the wheel pits.

The pressure pipes and exciter branches are below the level of the switch-board floor, obviating the use of short goose necks on the main units. The tailraces provide a straight outlet for the waste water in direct line with the axis of the pressure pipes and offer head room for repair work under the wheel mounting. Work can be done on either unit without interference with the operation of the rest of the plant. Wire conduits for the leads from the generators to the low-tension busbars and exciter circuits are designed with ample working dimensions. The reasons for the arrangements adopted will be taken up in connection with the several classes of apparatus to which they appertain.

Hydraulic equipment.—As designed, the water-wheel centers are mounted on the shaft on which the revolving fields of the generators are carried, dispensing with an intermediate coupling, and are fitted with interchangeable single tangential buckets. The shaft is carried in three bearings of the usual ring-oiling type. The wheel housings part horizontally at the axis of the shaft, permitting easy access to the entire wheel. The nozzles are interchangeable, equipped with deflecting hood actuated by means of rocker shaft and links from a Lombard governor belted to the generator shaft. The nozzles are also provided with a needle valve for hand regulation if desired. The exciter units, two in number, are connected directly to their respective water wheels, either being of sufficient capacity to provide exciting current for two generators. The exciter tailwater will discharge into the main tailraces. The foundations for water wheels and generators to be excavated to solid rock, built up with concrete, and reenforced and tied together laterally with expanded metal and small I beams.

Generators.—The generators proposed, three in number, are of the 3-phase, 60-cycle, alternating-current, revolving-field type, with a normal capacity of 1,350 kilowatts, or 1,800 horsepower, at 2,200 volts, at a speed of 200 revolutions per minute, and are on the shaft with the water wheel. The stationary armature in this form of generator dispenses with any adjustment of moving parts on the generating element of the machine, as the leads simply connect to terminal blocks on the armature frame to which the ends of the 3-phase windings are brought. The elimination of collector rings, made possible in this way, tends to higher generating pressures, with resulting economy in transformers. Machines of this type of 12,000 volts capacity have already been developed and are in successful operation.

In designing these works moderate electric pressures have been adopted both for generation and transmission, with a view to keeping well within the limits of successful operation. As planned, the generating units are below the station floor, to permit the pressure pipes


3'
6'
B

to reach the wheels without unnecessary curvature, and plenty of working room has been provided around, under, and over the machines. A traveling crane provides means to lift and transport any part of the machines to any part of the building. The generator leads pass up from the subterranean working conduit behind the switch board to the busbars, where they are distributed to the transformers overhead. Wide passageways are provided around the switch board, which consists of a separate panel for each generator and one for the exciters, carrying the usual interconnecting switches, voltameters, ammeters, integrating wattmeters, fuse blocks, field rheostat, and synchronizing devices.

Transformers.—The floor or shelf on which the transformers are placed is of concrete and expanded metal, with working room between and around the transformers. The low-tension wires (2,200 volts potential) pass into the transformer coils on the rear, next to the wall of the building, and the high-tension wires (30,000 volts potential) are taken from the opposite side through a plug board equipped with long break switches, from which the wires pass back overhead, across the transformers, through glazed openings, to the external circuits.

POLE LINES.

The route selected for the pole lines follows in a general way the proposed wagon road from the power house to Millwood, and thence along the existing wagon roads to Centerville, in the valley below, for the purpose of insuring access to the lines during the winter, when the ground will be covered with snow. Beginning at an elevation of 2,000 feet the line attains an altitude of 5,500 feet at Millwood, and then descends to Centerville, 45 miles from the power house. Experience in Colorado and British Columbia demonstrates that if the lines are structurally strong no interruption of operation need occur by reason of snow. Interruption has invariably been due to weak mechanical construction and not to electrical causes. Two pole lines carrying four 3-phase circuits of No. 3 hard-drawn copper wire supported on suitable insulators to be built to Centerville, where a switch station will be located. The arrangement is such that each generator can be run separately on an independent circuit, or any number of circuits can be operated in multiple from a single generator, or all of the generators can be run parallel into any or all of the circuits by means of suitable connection at the busbars. From Centerville one line has been projected to Fresno and beyond and another to Hanford and the intervening lands.

SUBSTATIONS.

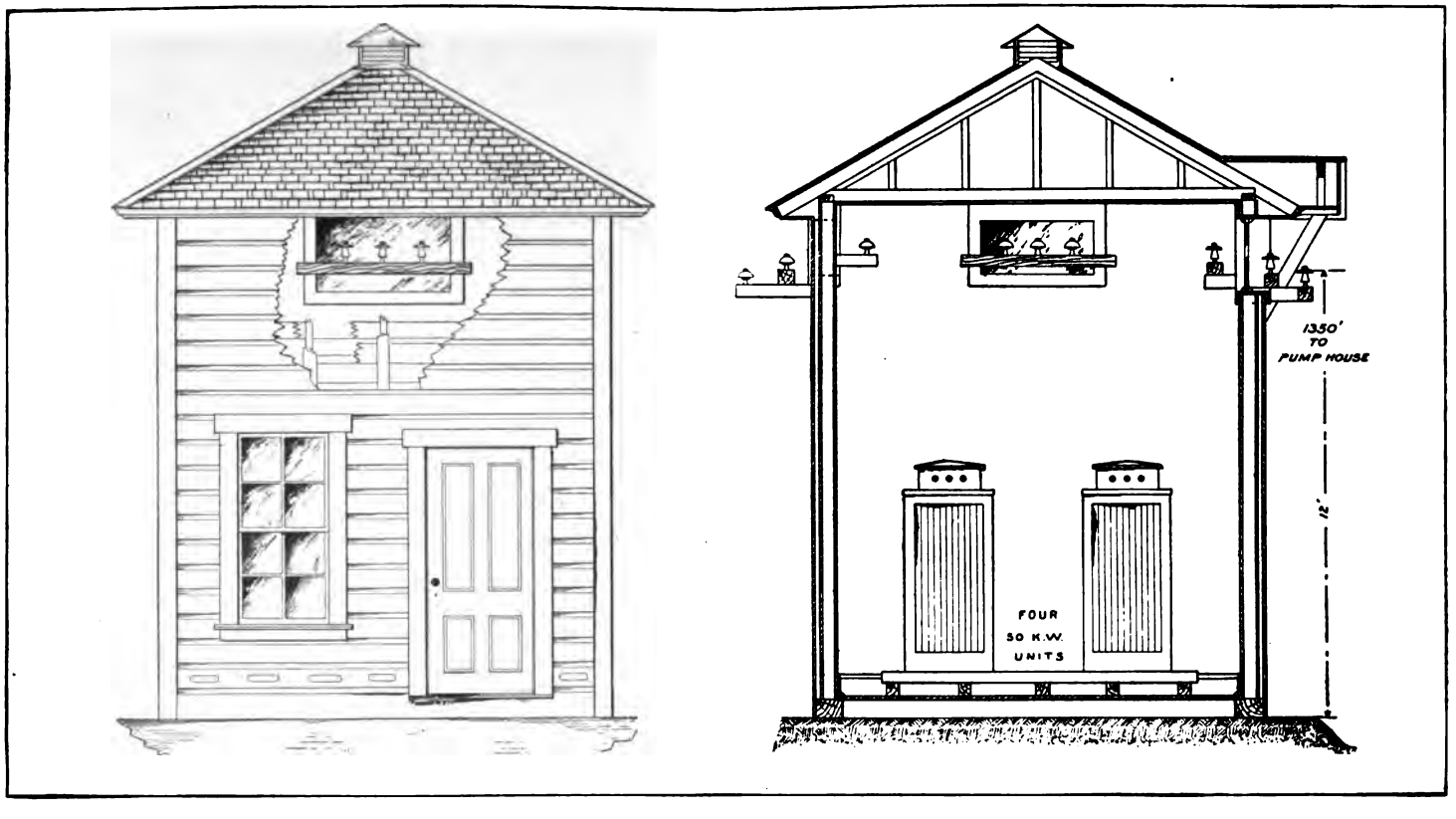
The extraordinary yield of the developed wells around Fresno, considered in conjunction with the depth to the plane of saturation, the probable depth of exhaustion of the wells, and the economical output for each station, requires about 45 horsepower delivered to the motors,

and the necessary size of the units suggests the use of 50-horsepower induction motors at 2,000 volts potential. The advantages of a large irrigating head have been obtained by grouping four pumping plants around a transformer station 800 to 1,200 feet distant. Each substation consists of a neat wooden building provided with a radiation wall so arranged that the heating of the air in the roof space creates a draft through the vent provided at the top, which establishes a circulation through the walls of the building and prevents the air within from attaining more than the normal temperature outside. The transformer house proposed is shown in elevation and section in Pl. XXX, and a section of its wall in Pl. XXXI, *B*.

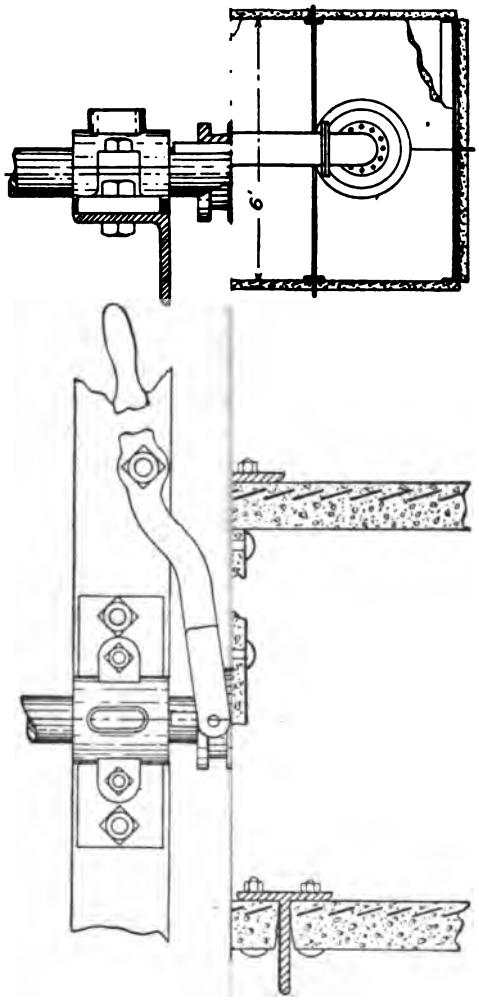
The equipment proposed consists of 200 kilowatts of self-cooling, oil-insulated transformers wound to convert the line pressure of 30,000 volts to a distribution potential of 2,000 volts, at which it is fed direct to the motors without further transformation. An outside high-potential, triple-pole, double, long-break switch provides means of cutting out the substations for adjustment.

PUMPING STATIONS.

These buildings are of the same general construction as the transformer house (For elevation and section of proposed pump house see Pl. XXXII.) As designed, the equipment consists of a 10-inch centrifugal pump, with working vanes to suit the motor speed and height of lift, mounted in a steel frame, connected directly, with grip couplings, to the shaft of a vertical motor supported on the same frame above the level of the surrounding country, so that in case the pit is accidentally flooded the electric apparatus is safe from injury and the plant suffers no damage. The pits are curbed with concrete and expanded metal panels set in steel T-beam frames and bolted in place, with diagonal bracing at the ends to prevent racking. (See Pl. XXXI, *D*.) The wells are 12 inches in diameter, sealed into the concrete floor, and will probably require sinking to an average depth of 100 feet. The suction pipes are 8 inches in diameter, of heavy galvanized iron, riveted and soldered. Suction inlet to the pumps is provided in the form of a cross, so that four wells, 90 degrees apart, can be connected. If the two wells shown in the section of the pit fail to develop sufficient water, another well will be sunk 30 or 40 feet away, laterally, and a fourth, on the opposite side, if it should prove necessary; these lateral wells to be connected by tunneling from the main pit, sinking a brick manhole over the well to the depth of the pit, and connecting the wall of the pit and the manhole by standard screw pipe surrounded by 6 inches of concrete, back-filled solidly and terminating at either end inside of the pits with a bolt flange from which connection can be made to the pump and vertical suction pipe. Priming is effected by closing the gate valve on the discharge pipe and exhausting the air from the suction pipes and pump with a mechanical primer operated with a taper friction from



ELEVATION AND SECTION OF PROPOSED TRANSFORMER HOUSE.


6'

the motor shaft. (See Pl. XXXI, *A*.) The motor starts idle, the weight of the motor and shaft being carried on a collar working on ball bearings on the pump head until the appearance of water at the discharge of the priming pump indicates the priming of the main pump. The opening of the gate valve on the discharge pipe permits discharge to begin, and the pump is so designed and adjusted that the static lift operates to balance the suspended parts. Each station is equipped with an automatic device for cutting out the motors in case of a disturbance of the line. Oilers are arranged to require attention once in twenty-four hours; more frequent inspection has been shown by experience to be unnecessary.

COST.

In the following estimate of cost wagon freight from Sanger to Millwood has been figured at $9 a ton, and from Millwood to the power house at $2 a ton. The figures used for the cost of the intake, conduit, roads, bridges, and trails were prepared from preliminary surveys, and appear to the writer to be ample to cover any probable modification of design or location. The delivery of construction material on the line of the tunnel and at the penstock requires the use of an inclined skidway and a small hoisting engine, which are included in the estimate. Several miles of difficult mountain wagon road and trails must be built, and a bridge be constructed across the South Fork at the power house. A screen of iron bars at the intake has been included in the estimate, also double screens at the penstock, to keep leaves and sticks from entering the pressure pipes. A telephone line of No. 12 wire, strung on the power line poles and equipped with instruments and cut-out switches at each of the substations, has been estimated upon, while a comfortable bunk house, with double roof and walls, library, dining room, kitchen, bathroom, and complete sanitary plumbing, which has been included, is regarded as a necessary adjunct, and a small ice-making plant and cold room piped for direct ammonia expansion, which have also been included, would add to the comfort of the employees.

Estimate of cost of power and pumping plants for generating and transmitting power from Kings River for the utilization of ground water in the valley.

Hydraulic works:		
Headworks and intake	$5,500	
Conduits	184,800	
Adits	7,700	
Sand traps	1,330	
Penstock and waste weir	3,478	
Pressure pipes (three steel pipes, each 30 inches in diameter, 3,200 feet in length, with gates and air valves)	59,691	
Hydraulic equipment (water wheels for the three generators and the two exciters, with governors, gates, and fittings)	27,000	
		$289,499

Buildings:		
Power house, foundations, and conduits	$15,738	
Mess and bunk house	3,600	
Refrigerating plant	1,500	
Stable, workshop, and tools	2,900	
		$23,738
Roads and bridges	58,850	
Trails	3,300	
		62,150
Electric generation and conversion:		
Generating equipment and control (three generators, 1,800 horsepower each, two exciters for same, switch board, instruments, and installation)	59,705	
Transformers (ten of 600 horsepower each, 30,000 volts, with switches, etc.)	33,000	
		92,705
Transmission:		
Pole lines (45 miles of double pole line, four circuits to Centerville, 45 miles distant, and 40 miles of distribution lines)	267,200	
Centerville switch house	3,000	
Substation transformation (25 substations, each containing four step-down transformers—one for reserve—total capacity 266 horsepower, with switches, etc., complete, each station designed to furnish the power for four pumping stations)	73,750	
		343,950
		812,042
Engineering and contingencies, 5 per cent		40,602
Total		852,644
Pumping stations, 100 at $4,057 (consisting of 50-horsepower motor, 10-inch centrifugal pump and attachments, cement-lined pump pit, four wells 90 feet deep, buildings, piping, etc.)		405,700
Engineering and contingencies, 5 per cent		20,285
Total		425,985
Recapitulation:		
Power generation and transmission		852,644
Water development, i. e., 100 pumping stations		425,985
Total		1,278,629

The estimate on pumping plants is for a capacity of 5 second-feet each, or a total of 500 second-feet, per 24 hours, being 1,000 acre-feet per 24 hours from an average depth of 45 feet, equivalent to 365,000 acre-feet per annum (365 days), making the cost of installation $3.50 per acre-foot of annual capacity.

The estimated cost of operating the plants is as follows:

Estimated cost of operating power and pumping plants.

Interest, 6 per cent on bonded indebtedness	$76,718
Taxes, 2 per cent on 60 per cent valuation	15,343
Depreciation and maintenance	25,550
	117,611

Power house:		
One superintendent	$1,400	
Three attendants at $1,000	3,000	
Three helpers at $800	2,400	
One laborer	750	
One watchman	750	
Horses and stable	1,300	
Oil, waste, and supplies	2,400	
		[a]$12,000
Pole line:		
Two linemen	1,800	
Teams and supplies	800	
		2,600
Pumping stations:		
Ten attendants at $800	8,000	
Two inspectors at $1,000	2,000	
Horses, 20 at $150	3,000	
Oil, waste, and supplies	2,400	
		15,400
Total operating expenses		30,000
Administration and local expenses:		
One general superintendent	2,400	
One bookkeeper	1,200	
Office rent and sundries	1,400	
		5,000
Insurance and contingencies		5,000
		10,000
Total		157,611

Considering the load factor of the pumping system, i. e., the ratio of the average load to the maximum load, to be 90 per cent, the annual pump output would be 328,500 acre-feet, on the basis of the use of the plant for 328½ days, and the total cost of operating would amount to, in round numbers, $0.50 per acre-foot produced per annum. If the plant were operated fewer days each year the cost per acre-foot produced would be much greater.

CONCLUSION.

In order to appreciate the magnitude of the proposed development it may be compared with what has already been achieved with the gravity flow of Kings River. The flow available during dry years is the measure of irrigated acreage on which stable values can be maintained, since land with an uncertain water supply must fluctuate in value as the seasons are favorable or otherwise. During 1898 the supply available was very deficient. Last year (1900) the profits from the raisin crop alone in the Fresno district are reported to have been more than $2,000,000, and this industry, as well as the fruit, stock, and general farming interests, is dependent on the river, not partially but absolutely, for its existence. Practically all created values within the area served by the water of Kings River are sustained by its

[a] Operatives to pay cost of board at mess house out of salaries.

flowage, and the aggregate of these values runs into millions of dollars. Plenty of additional land, of even better quality than that now under cultivation, is available if an assured water supply can be provided.

Making due allowance for seepage losses in conveying the pumped water, the annual amount available from the new supply would be 300,000 acre-feet, and the cost of supplying it would be only slightly in excess of the present charges for water from gravity canals in this locality.

The conditions described exist at many other places along the eastern slope of San Joaquin Valley, where there are many square miles of unused land, much of it possessing as great natural advantages as the tracts under cultivation at lower elevations, which a water supply would convert into a rich and productive country. Riverside is an example of what five years' development with water will accomplish. Notwithstanding the continued decreasing flow of the perennial supply due to the dry years 1895 to 1900, orange planting, which passed the natural limit of stream flow several years ago, has been steadily extended to outlying districts, and water development from well supplies has kept pace with the increasing requirements until the quantity available and the acreage served are much greater than ever before, and the best lands are now dependent on pump irrigation.

General attention now being directed toward the advantages possessed by California, it seems probable, under the pressure of increased population and the market demands which must follow, that another generation will witness the cultivation of every acre of land susceptible of irrigation in San Joaquin Valley, and in view of the possibilities herein suggested it does not appear unreasonable to believe that water will be provided for every acre that can be cultivated.

SUMMARY.

The important results of the investigations on Kings River are summarized in the following table:

Results of investigations for water development along Kings River.

Improvement.	Description.	Capacity, in acre-feet per annum.	Cost of installation.		Annual cost, per acre-foot, of interest and operation.
			Total.	Per acre-foot stored.	
Dusy Meadows reservoir.	125-foot dam	16,850	$538,860	$32.00	$3.10
Pine Flat reservoir	140-foot dam	78,197	1,750,000	22.38	2.06
Clarks Valley reservoir.	85-foot dam	120,499	1,331,025	11.05	1.04
Do	105-foot dam	217,196	2,206,822	10.15	.92
Long Meadow reservoir.	170-foot dam	25,334	713,715	28.00	2.64
Pumping plants	328½ days' operation per annum.	328,500	1,278,629	3.50	.50
Do	100 days' operation per annum.	100,000	1,278,629	12.78	1.43

The last column of the foregoing table gives the cost per acre-foot per annum of water delivered to the lands to be irrigated, a deduction of 20 per cent of the water stored being made for losses by evaporation and seepage in transit. The pumping plants being located where the water will be used, no such deductions are made for them.

The Dusy Meadows and Long Meadow reservoir sites are not of special value, as better reservoir sites are available. The Pine Flat and the Clarks Valley sites, however, are both of great value to the Kings River irrigation districts. The storage work should be begun by building the Clarks Valley reservoir with the 85-foot dam. This should be followed by the construction of the 140-foot dam at the Pine Flat site. The height of the dam at Clarks Valley can be increased to 105 feet or more in the future. Water from these reservoirs could most advantageously be applied to the foothill lands between elevations of 300 feet and 550 feet, where citrus fruits can be raised and where no water is now available.

The estimates show that the cheapest supply in the valley can be obtained by pumping with electric power generated by the river itself before it reaches points of diversion or storage, provided the pumping plants are operated at least half the time. This pumped water could be obtained most cheaply in the lower valley lands, where the water plane has now risen to near the surface and where the longest diversions are necessary under existing canals. While the pumping plants might be used near the foothills the water supply there would not be so large and the lifts would be greater, but the lands redeemed would be more valuable.

During the high-water stages of the river, which last from March until the middle of June or the first of July, an abundance of cheap water is now available by gravity for the irrigation of all of the lands within reasonable limits which are under Kings River. At present the use of the water is needlessly wasteful during that season of the year. It is believed that if, in addition to this spring irrigation, water to a depth of 1 foot could be furnished to the irrigated lands between the first of July and the end of November it would be sufficient to maintain them in a condition for the production of any crop. Assuming that the pumping plants will produce 200,000 acre-feet of water, there will be available from that source and from the Clarks Valley and Pine Flat reservoirs, with the lower dams, about 400,000 acre-feet of water. If all the water that is diverted by the pumping plants and the storage reservoirs should be put onto new areas it would mean the addition of 200,000 acres of irrigated land to the community.

In concluding it may be stated—

(1) The capacity of the canals diverting water from Kings River is approximately 4,000 cubic feet per second.

(2) Ten years' records of the river show that the average flow for the month of August is 603 cubic feet per second and for the month of September 389 cubic feet per second.

(3) The irrigable area is very great.

(4) Probably the most valuable areas in Fresno and Tulare counties are the foothill lands upon which citrus fruits can be grown between the 300-foot and the 600-foot contours of elevation. These lands are without water rights and can be irrigated from the reservoirs described herein.

(5) Pumping plants can be established and operated which will furnish 1,000 acre-feet of water per day at a cost not much greater than that now paid for gravity water from the canals, to supplement the present summer supply or to extend the irrigated areas.

(6) The operation of the pumping plants will partially if not wholly prevent the rising of alkali to the surface of irrigated lands.

(7) One hundred and ninety-eight thousand six hundred and ninety-six acre-feet of water now wasting annually can by storage be conserved at prices well within commercial limits.

(8) A good water right will add $50 per acre to the value of dry lands in the valley and $90 per acre to the value of lands in the foothills.

(9) All of the works included in the table on page 96 are feasible and safe from an engineering point of view.

ACKNOWLEDGMENTS.

Acknowledgments are due to Mr. H. E. Green, who had charge of one of the field parties and rendered excellent service in that capacity, especially in the arduous and dangerous survey of the canyon of the Middle Fork of Kings River, and who also assisted in the preparation of the estimates and plans for the dams and power conduit; to Mr. J. H. Quinton, who assisted, as consulting engineer, in preparing the plans and estimates; to Mr. Lewis A. Hicks, who made the estimates of the cost of installing the electrical machinery and the pumping plants, which from his experience in that line of work on Kern River are of special value; to Mr. Thomas Means, assistant in the Division of Soils of the United States Department of Agriculture, who has given valuable information concerning the alkali conditions; to Mr. E. G. Hamilton, topographer from the United States Geological Survey, who was in charge of the reconnaissance party; to Mr. Louis Mesmer, who compiled the data concerning the wells and the tests thereof; and to Messrs. W. H. Ingells and L. A. Nares, who have furnished a great deal of general information concerning the local conditions and the irrigated areas.

ADDENDA.

In the summer of 1901 a series of measurements of some of the canals taking water from the north bank of Kings River and east of Centerville were made for Mr. L. A. Nares, general agent of the Fresno canal. This is nineteen years subsequent to the measurements made by Mr. Grunsky, and the results are in marked contrast with those obtained by him. Evidently the continued irrigation practiced during the interval has raised the ground-water level so that it is largely supporting the water in transit in the canals. While in some instances gains in the volume of water are reported, it is believed by the writer that these must be the exception instead of the rule, for the canals are normally higher than the lands irrigated, and there can not be a gain unless the plane of saturation is higher than the surface of the flowing water.

These measurements are of interest, but owing to continued diurnal fluctuations in both the river and the canals absolute results can only be obtained by continuous records of water heights at rating stations.

Summary of measurements made in Kings River canals in August and September, 1901, to determine loss or gain by seepage and evaporation.

No. of measurement.	Name of canal.	Locality.	Distance.	Gain or loss.	
			Miles.	*Sec.-feet.*	*Per cent.*
1	Centerville and Kingsburg canal.	Centerville to Sanger	7	−20.00	− 5
2	Fowler Switch canal	Centerville to Collins Gate	9	+ 6.00	+ 2
3	do	Head gate to Centerville	2	+	+
4	do	Centerville to Collins Gate	9	− 9.57	− 8
5	Centerville and Kingsburg canal.	Centerville to Sanger	7	−33.00	−12
6	Gould canal	Holland Flume to Kutner Colony.	11	+ 2.25	+ 1
7	do	do	11	+ 1.50	+ 2
8	Main canal	Long Cut and Limbaugh Gate.	10	−27.65	− 7

NOTE.—All of the measurements except Nos. 4 and 5 were made with a current meter. Plus sign (+) indicates gain, and minus sign (−) indicates loss.

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DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 59

WASHINGTON
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1902

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

DEVELOPMENT AND APPLICATION OF WATER NEAR SAN BERNARDINO, COLTON AND RIVERSIDE, CAL

PART I

By JOSEPH BARLOW LIPPINCOTT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1902

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., June 29, 1901.

SIR: I have the honor to transmit herewith a manuscript concerning the development and application of water in southern California, prepared by Mr. J. B. Lippincott, resident hydrographer for this Survey in California. This paper describes the general conditions of water supply in an important and densely populated agricultural area, where water has probably the greatest value for irrigation of any part of the United States. The data are of particular interest because of the development made during the series of dry years which culminated in 1890. Every possible expedient was resorted to for economizing or increasing the supply of water; tunnels were driven into the hills, dams were built to bed rock in the canyons, and wells were dug or drilled throughout the valleys. Almost every conceivable device for pumping water has been employed and great ingenuity displayed in bringing water to the orchards and more valuable crops.

The details of some of the works and wells have been brought together by Mr. Lippincott and form an exhibit of results accomplished under conditions where water has great value. The results are instructive, as showing what may be done in other parts of the United States under favorable conditions of climate and soil, and have peculiar interest in any consideration of the extent to which the Arid Lands can ultimately be redeemed by irrigation.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

117°30′

DEVELOPMENT AND APPLICATION OF WATER NEAR SAN BERNARDINO, COLTON, AND RIVERSIDE, CAL.

PART I.

By JOSEPH BARLOW LIPPINCOTT.

GENERAL LOCATION AND TOPOGRAPHY.

Owing to the uniformity and mildness of its climate, the grandeur and diversity of its scenery, and the great variety and vigor of its vegetation when furnished with moisture by irrigation, southern California has become the pleasure ground of the United States. In its semitropical valleys, lying between snow-capped mountains and a mild sea, art, refinement, and wealth have combined to make beautiful homes. The narrow strip of land lying between the mountains and the sea is fast becoming the Riviera of America. San Bernardino Valley is its garden, furnishing many varieties of deciduous and semitropical fruits for Eastern and domestic markets. Riverside and Redlands are the two principal centers of fruit production.

This valley is protected from the cold winds off the desert on the north and east by the Sierra Madre and San Bernardino Range, the elevations of the crests of which vary from 5,000 to 10,000 feet. To the south and west the valley is inclosed by low mountains, which form a secondary coast range, the highest peaks of which are in the Temescal Range to the south, the lowest in the San Jose and Puente hills to the west. The latter separate San Bernardino Valley from San Gabriel Valley and the Santa Ana coastal plain. San Bernardino Valley somewhat resembles a right-angled triangle, the apex being at the point where Santa Ana River leaves the mountain range, the base extending from Corona to Lordsburg, 24 miles distant, the right angle being at Corona, and the height 32 miles. The area of the valley is 563 square miles. The streams enter it from the north and east, coming from the Sierra Madre and the San Bernardino Mountains, with the exception of San Timoteo Creek, which discharges about 1 second-foot in summer, and Temescal Creek, which irrigates 3,600 acres.

The Riverside district is on the south side of the valley and is irrigated from return water, from pumping plants, and from artesian

wells. The city of San Bernardino and its surrounding neighborhood are similarly supplied, supplemented also by Lytle Creek. Corona is irrigated from Temescal Creek and from local wells, supplemented by a pumping plant and pipe line from the water-bearing lands of San Jacinto Valley. All of the remaining orchards and gardens of San Bernardino Valley are on the northern and eastern edge of the valley and are supplied from local mountain drainage basins.

During years of average stream flow the duty of water for citrus fruits may be taken at from 5 to 8 acres to the miners' inch (0.02 second-foot), continuous flow, when good service is rendered, and double that area when used for deciduous trees.

All of the streams issuing from the north side of the valley have assisted in building up a bench-like mesa of débris cones of granite material, which varies in elevation from 800 to 1,200 feet above the thalweg of the valley. The northern rim of the valley at the foothills is at an elevation about 2,000 feet above sea level and the southern rim at an elevation of approximately 1,200 feet. On the southern side of the valley the mesa which lies next to the foothills is formed to a large extent from disintegrated granite mingled with red clays from San Timoteo Canyon and adjoining hills. Upon this bench are Riverside and Redlands, and it is from the red soil that the latter district derives its name. The Riverside bench is from 100 to 300 feet above the river bed and from 850 to 1,000 feet above sea level. It is 20 miles long and about 5 miles wide.

Water is the life blood of the land. Without it there can be no substantial growth, except occasional crops of grain, and this region would become a semidesert. We therefore find (see map, Pl. I) the towns and orchards clustered around the mountain edges, the canyons from which the streams issue, or in the lower depressions of the valley toward which the underground and return water from irrigation gravitate, to appear again for use on the surface, as at Colton and Rincon. The intermediate lands remain mostly unused and uncultivated, a few cattle to the section or an occasional crop of grain being all they will support. The highly productive portion of the valley is limited by the amount of water that is available for irrigation. All of the summer and much of the normal winter flow of the streams has now been appropriated and diverted, and it would seem that the valley had reached its limit of irrigated land from that source. However, in the lower valley lands the extensive saturated gravel beds will be drawn upon to supplement the surface supply, especially during dry years. The precipitation occurs almost entirely between November and April, and in normal years varies from 10 inches in the valley to 50 inches on high mountains. The minimum is as low as 33 per cent and the maximum as high as 200 per cent of the mean. The discharge of the streams is relatively large

in winter and low in summer. The increase of the summer water supply is dependent upon the construction of reservoirs in the mountains, to store the winter storm water, or upon the development of water by wells or excavations in the valley lands.

The map accompanying this report (Pl. I) shows, by shaded areas, the land actually under irrigation and supplied or partially supplied with water during the summer of 1900. No effort has been made to distinguish between good and poor water supplies. The irrigated areas were determined by actual field observations, those in the Redlands quadrangle by Mr. Louis Mesmer, and those in the San Bernardino quadrangle by Mr. C. J. Roney, both of Los Angeles. The various irrigation canals and the principal distribution lines are also indicated on the map, as well as the locations of the power plants on Santa Ana River and Mill Creek, the approximate location of the water plane for the summer of 1900, and the locations of the wells. The numbers on the map correspond with the numbers of the wells in the table on pages 115 to 134 (Part II). Where isolated wells occur and the information is not sufficient to contour the water plane, its elevation is given (black figures) on the map.

SOIL.

The soil of the valley is of two distinct classes, the bench or delta-like lands around the rim of the valley and the moist bottom lands. The former merge from mere piles of rocky bowlders and sand containing little humus or soluble matter but which are capable of growing orchards, to sandy loams such as are found around Riverside. They are very deep and apparently of the same chemical composition in the lower strata as at the surface. They are warm and porous, and on such surface gradients that they are well drained, so that there is no danger to either the crops or the health of the cultivator from a rising and stagnant water plane with its accompanying alkali. Prof. E. W. Hilgard, professor of agriculture at the University of California, furnishes the following analyses of the Riverside soil and subsoil:

Analyses of soil and subsoil at Riverside.

	Soil, depth 12 inches.	Subsoil, depth 9 to 10 feet.		Soil, depth 12 inches.	Subsoil, depth 9 to 10 feet.
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*
Coarse materials	20.000	23.000	Alumina	5.296	5.078
Fine earth	80.000	77.000	Phosphoric acid	.141	.159
			Sulphuric acid	.001	.001
Insoluble matter	76.410	75.445	Water and organic matter	1.600	1.440
Soluble silica	8.204	8.066			
Potash	.869	.928	Total	99.947	100.172
Soda	.293	.360	Humus	20.000	.....
Lime	1.568	1.727	Available inorganic matter	64.000	.....
Magnesia	1.325	1.581	Available phosphoric acid	.015	.....
Brown oxide manganese	.040	.041	Hygroscopic moisture absorbed at 16°C	1.77	2.160
Peroxide iron	4.200	5.338			

In the lower portions of the valley, where the water comes to the surface, the land is moist enough for cultivation without irrigation. Fields of alfalfa are thus grown around San Bernardino, Colton, and Rincon, and it is upon land of this character that the Chino beets are raised. Where the subdrainage is poor the continuous evaporation from the surface of the soil of water that is but slightly charged with sodium, carbonate, and sulphate will ultimately produce an alkali soil. This has occurred frequently in these localities. It is claimed, however, that the sugar beet will thrive on land somewhat alkaline, and this is said to have been demonstrated at Chino. In these bottom lands some adobe is found, but it does not cover extensive areas. The remedy for this alkali condition will probably be found in drainage and in the use of gypsum.

CLIMATE.

It has been said of southern California that every township has a distinct climate. It has taken years of time and the expenditure of thousands of dollars to determine the frost line. There is no protracted cold weather in San Bernardino Valley. A temperature of 26° F. maintained for several hours will freeze and ruin an orange or lemon crop, a temperature of 18° will kill young trees, and a temperature of 14° maintained over night is sufficient to kill old trees. These low temperatures are reached only during the night. The isotherms follow topographic contours within certain limits. The frost and cold settle into the relatively low lands, but other local conditions tend to modify this physical phenomenon.

The air over the desert east of the mountains is raised to a relatively high temperature during the daytime and is forced upward. In the citrus belts frost usually occurs when a high barometric pressure exists over the desert, producing winds away from that locality. The air currents that are forced over the higher mountains are chilled and frost is found along the depressions of the canyons leading from their crests, while the drafts of desert air passing through the low passes are warmer. The areas affected by frost vary from year to year and no exact isotherms can be drawn for all years. After entering the valley the cold air, being relatively heavier, gravitates to the lower levels. The north wind from the Cajon Pass, which protects Rialto, Riverside, and Bloomington, seems to force the colder air which gravitates toward the lower portions of the valley around Colton into the extreme lower portion of Santa Ana Valley.

Up to elevations of 2,000 feet the relatively high lands are free from frosts and the relatively low lands are subject to it. For instance, in the Del Rosa and West Highlands districts the lands south of the track of the Southern California Railroad are considered unsafe for oranges while those above it are relatively free from frost. The

neighborhood of the town of San Bernardino has been largely abandoned as a citrus district and converted into dairy, vegetable, and deciduous-fruit farms. This determination of the frost line is a subject of vital importance to those intending to cultivate citrus fruits, and can not be studied with too much care. After orchards have been developed it has often been found that they are not within the thermal belt, and vigorous efforts have been made to remedy the evil. Thermometers which ring alarms when the mercury drops below 32° have been constructed and placed in the orchards. A common practice is to burn brush or coke, or otherwise produce a smoke, so as to raise the temperature a few degrees and prevent freezing. Wind, if there be any, tends to mitigate the frost. In some localities ignited jets of crude oil or distillate, 15 to the acre, have been tried and have raised the local temperature 3°, but even this is uncertain, for the wind blows away the warmer air and the burning oil smuts the trees. When this method is adopted oil tanks are placed in the orchard and distribution pipes are laid to the jets throughout the groves. A unit of water in freezing gives off sufficient latent heat to raise the temperature of an equal unit of water 142° F. In order to use the latent heat thrown off in freezing, Mr. A. J. Everett, of Riverside, tried discharging sprays of water above the trees when the temperature of the atmosphere fell below 32°. The result, however, was a failure, the trees becoming coated with ice and the limbs being broken, with no resultant benefit.

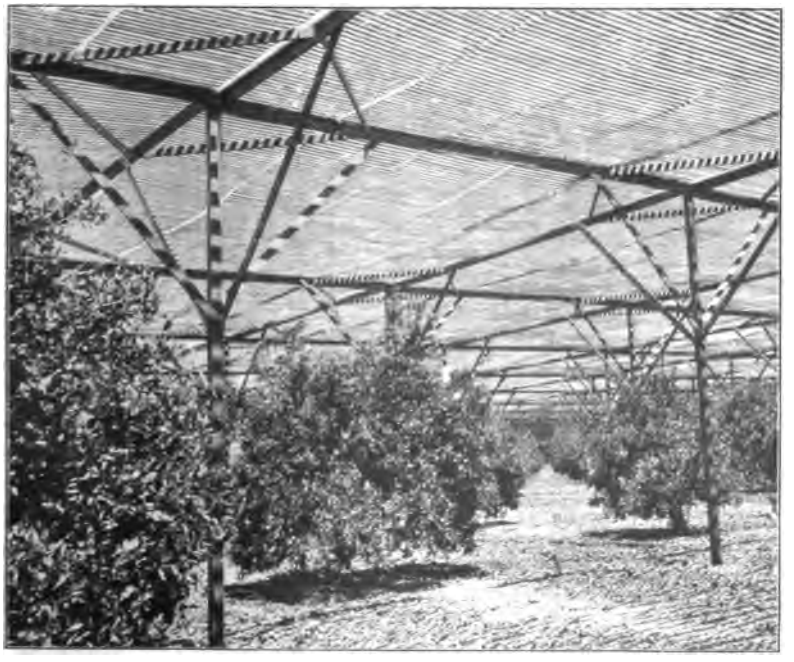
The most successful efforts in the protection of orchards from frosts have been those of Mr. Everett, who covered 15 acres of orchard with lath fencing, half the space being open, as shown in Pl. II. The day temperature under the screen is found to be as high as that outside. The theory is to hold the day temperature of the earth under the screen as long as possible at night, or in other words to impede radiation. The shade afforded by the screen also tends to prevent rapid thawing of the fruit and the expansion of the liquid in the fruit cells at sunrise, which bursts the cells and spoils the fruit. Without fires under the screen the night temperature is held 6° above that of the outside atmosphere. In one instance, with an outside temperature of 19° and with ten coke fires to the acre distributed under the screen in wire pots holding about 1 cubic foot each, the temperature under the screen was kept at 29° during the night, and it is said that it could have been kept at 32° except for carelessness. In the fall of 1897, 75 trees in the coldest portion of an orchard were covered and the crop was saved. Part of the trees were covered with canvas over the lath and part with lath only, the results being equally beneficial. Outside the screen both crop and trees were frozen and in some instances the trees were killed. Inside the screen the St. Michael oranges, the most delicate, were saved. The crop, however, does not ripen as quickly under the screen as outside. With lumber at $20 a

thousand the cost of building the screen is approximately $425 to the acre. The uprights are 3 inches by 4 inches by 15 feet high, and are set 21.2 feet apart. The top members are two 1-inch by 4-inch boards edged in T shape. The top of the screen is of lath commonly used for chicken-yard fences, openings the width of the lath being left between them. The high cost of this cover has prevented its being generally used.

A more even temperature exists nearer the seacoast than in San Bernardino Valley, and for winter vegetables and deciduous fruits that may be the better location, but not for citrus fruits. In the interior valley the temperature during the summer rises from 30° to 40° higher than on the coast, and high temperatures are necessary for the production of a sweet fruit. The cooler coast temperatures and fogs also tend to cause the citrus fruits to grow a thick-skinned, pulpy-celled lining. The higher temperatures are also unfavorable to the scale pest, which is the insect enemy to citrus fruits. The black scale exudes a sticky substance, which falling on the leaves and fruit retains the dust and gives the trees and fruit a dirty appearance. In the interior valleys the scale is not found. Generally speaking, in southern California the best citrus fruit is grown 30 or more miles from the coast, on the western slope of the mountains, and at elevations from 600 to 1,800 feet above sea. The conditions mentioned have greatly restricted the area where citrus fruits can be grown at a profit, and this area may be said to be decreasing rather than increasing. The general development of the country and improved transportation facilities are tending to enhance the value of really first-class citrus lands. It must be remembered that the determination of the frost line has been a slow process, but it is gradually being located, and the newer groves are planted in more propitious places. The groves located within the frost belt are chiefly old seedlings, now in full bearing, so that the loss from freezing is relatively much larger now than it will be ten years hence, for the old orchard lands that have been found frosty will be put into different crops or their water rights be transferred to other and better located lands. It is safe to say that throughout San Bernardino Valley much more land will be found adapted to this class of horticulture than the water supply will serve.

From the following tables of rainfall and temperature it will be seen that during the summer, or growing season, there is an absence of rain. In fact, from April 1 to November 1 there is practically continuous sunshine. The atmosphere also is very dry. These two conditions produce a rapid plant growth when water is abundantly supplied by irrigation. Vegetation develops with much greater rapidity under these conditions than at similar latitudes in the Eastern States.

A GENERAL VIEW OF FRAMEWORK OF SCREEN FOR PROTECTING ORCHARDS FROM FROST AT RIVERSIDE.



B. FROST SCREEN AS SEEN FROM BENEATH.

Table of temperatures, in degrees Fahrenheit, at Riverside.[a]

Year.	Jan.		Feb.		Mar.		Apr.		May.		June.	
	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.
1890	66	26	82	28	83	32	93	36	96	38	108	44
1891, mean	49.3		48.0		53.8		57.8		60.3		67.6	
1892, mean	53.4		53.8		56.6		59.8		64.9		68.2	
1893, mean	52.5		50.4		51.5		60.7		64.9		70.8	
1894, mean	47.3		48.4		54.2		60.3		62.4		63.8	
1895, mean	49.8		50.8		56.7		60.6		67.7		71.4	
1896	65.47	41.67	71.81	43.22	70.10	46.10	69.20	41.70	79.75	50.37	90.39	56.40
1897	75	35	76	31	80	28	93	36	93	44	100	48
1898	83	30	96	36	83	31	104	36	73.2	47.6	99	46
1899	65	40	86	28	88	32	96	36	90	38	102	46
1900	69	45	73	42	75	47	69.59	43.37	.....	.....	.....	.....

Year.	July.		Aug.		Sept.		Oct.		Nov.		Dec.	
	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.
1890	106	50	105	52	104	49	97	38	95	36	78	34
1891, mean	78.2		77.8		70.0		66.6		58.4		48.3	
1892, mean	73.1		74.3		70.4		62.0		59.5		51.0	
1893, mean	74.8		75.7		65.5		62.0		54.0		54.0	
1894, mean	75.2		74.4		71.6		64.8		61.5		53.2	
1895, mean	74.8		75.2		71.6		66.0		56.6		51.4	
1896	91.65	76.02	99.60	57.90	87.64	54.58	83.03	52.23	70.03	54.57	68.57	43.47
1897	102	50	108	52	100	46	84	42	89	35	86	27
1898	108	52	111	51	112	47	100	41	93	36	80	31
1899	108	49	108	49	107	52	94	40	84	38	84	35
1900	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

[a] Authority, Weather Bureau.

Record of precipitation, in inches, at Riverside.

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1880-81	0.00	0.00	0.20	2.26	0.48	0.25	1.30	0.74	0.03	0.00	0.00	0.00	5.26
1881-82	.10	.40	.25	.40	1.70	1.40	1.08	.72	.08	.18	.00	.00	6.31
1882-83	.00	.13	.29	.20	.09	.83	.89	.26	.25	.00	.00	.00	2.94
1883-84	.00	.97	.00	2.25	.84	7.94	6.56	1.67	1.99	.52	.00	[a]3.00	25.74
1884-85	.00	.12	.12	2.56	.77	.00	.01	2.15	.24	.00	.00	.00	5.97
1885-86	.00	.02	1.34	.62	2.68	1.38	1.95	1.43	.00	.00	.00	.00	9.42
1886-87	.00	.00	.54	.04	.13	3.30	.02	1.70	.17	.02	.00	.00	5.92
1887-88	.00	.75	.87	.85	4.17	1.05	3.84	.18	.05	.00	.00	.00	11.75
1888-89	.00	.00	2.83	3.37	.87	1.30	5.10	1.83	.25	.00	.00	.00	15.55
1889-90	.09	1.35	1.82	7.10	4.44	1.96	.60	.06	.09	.00	.00	.05	18.26
1890-91	.79	.13	.32	3.21	.13	6.36	.40	1.04	.46	.00	.00	.00	12.84
1891-92	.13	.03	.00	1.29	.00	2.60	1.07	.00	1.32	.00	.00	.00	6.44
1892-93	.00	.29	.28	.94	3.01	1.95	5.71	.29	.04	.00	.33	.00	12.79
1893-94	1.27	1.08	.67	2.05	.69	.33	.70	.00	.00	.00	.00	.26	7.05
1894-95	.20	.05	.00	5.22	6.48	1.09	2.54	.29	.26	.00	.00	.00	16.13
1895-96	.00	.00	1.25	.24	1.72	1.00	3.16	.56	.58	.00	.01	.02	7.54
1896-97	.00	2.07	1.48	.92	3.38	3.07	1.62	.03	.03	.00	.00	.04	12.64
1897-98	.09	1.67	.02	.95	1.41	.16	.62	.24	.30	.00	.00	.00	5.46
1898-99	.03	.00	.00	.62	1.81	.52	1.13	.10	.08	.53	.00	.00	5.00
1899-1900	.00	1.05	.68	.58	1.11	.00	1.11	1.32	1.04	.00	.00	.00	6.89
Mean	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	10.00

[a] Hail.

Record of precipitation, in inches, at San Bernardino.

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1885-86	0.00	0.39	4.36	1.20	6.34	2.52	4.18	2.36	0.32	0.16	0.00	0.00	21.83
1886-87	.00	.00	.11	.61	.39	6.44	4.41	1.90	.42	.22	.11	.04	14.50
1887-88	.09	1.17	2.29	1.91	4.01	3.60	3.41	.58	.52	.03	.00	.00	17.76
1888-89	.00	.05	4.12	4.64	.93	1.50	6.55	2.05	1.13	.00	.17	.63	20.97
1889-90	.11	2.30	2.23	10.85	5.44	2.52	.89	.00	.31	.00	.13	2.16	25.45
1890-91	.88	.58	1.27	3.02	.00	7.78	.06	.53	1.67	.00	.00	.91	18.08
1891-92	.93	T.	T.	1.67	3.24	3.30	1.75	.37	2.10	.08	.00	.00	14.35
1892-93	.00	.16	1.02	2.23	4.53	5.37	8.00	.48	.03	.00	.20	.00	19.82
1893-94	.05	1.05	.30	2.28	1.26	.88	1.15	.40	.56	.00	.00	.16	8.13
1894-95	.37	.15	.00	7.25	7.39	1.14	3.44	.64	.44	.00	.00	.00	20.98
1895-96	.00	.00	1.14	.66	2.02	.00	2.92	.37	1.00	.00	T.	.17	8.11
1896-97	.00	2.10	.98	1.09	3.40	5.40	3.41	.08	.01	.00	T.	.00	16.74
1897-98	.13	2.10	.21	.57	2.10	.60	.97	.48	1.08	.00	.00	.00	8.24
1898-99	.00	.03	.05	.44	2.03	.51	3.22	.07	.19	.95	.00	T.	7.49
1899-1900	.01	.81	1.47	.84	.92	.00	.12	.02	.00	.00	.50	.00	4.69
Mean	------	------	------	------	------	------	------	------	------	------	------	------	15.14

Record of precipitation, in inches, at Colton.

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1885-86	0.00	0.00	1.92	0.52	2.78	0.40	3.54	0.50	0.00	0.00	0.00	0.00	9.66
1886-87	.00	00	.80	.00	.21	3.64	.00	1.94	T.	.00	.00	.00	6.59
1887-88	.00	.00	.70	.80	1.43	2.15	3.68	.43	.00	.00	.00	.00	9.19
1888-89	.00	.00	2.37	3.26	.86	.88	4.47	1.02	.60	.00	.00	T.	13.46
1889-90	.04	1.59	1.26	7.41	.94	1.15	.50	.00	.00	.00	.00	.06	14.95
1890-91	.67	.00	.19	2.45	.00	6.48	.25	.80	.90	.00	.00	.00	11.74
1891-92	.00	.00	.00	.87	2.27	3.36	.80	.24	1.44	.00	.00	.00	8.98
1892-93	.00	------	.90	1.45	2.40	2.91	6.64	.16	.00	.00	.30	.00	14.76
1893-94	.00	1.18	.22	1.93	.20	.55	2.00	.10	.50	.00	.00	.00	6.68
1894-95	.45	.15	.00	5.70	2.88	1.00	2.94	1.08	1.05	.00	.00	.00	20.26
1895-96	.00	.00	1.16	.00	.10	.00	2.91	.25	.38	.00	.00	.10	5.90
1896-97	(?)	2.28	.94	1.11	3.52	3.96	2.70	.00	.15	.85	.00	.00	15.51
1897-98	.00	2.20	(?)	.30	1.48	.23	.80	.10	.34	.00	.00	.00	5.45
1898-99	.00	T.	T.	.45	1.57	.45	1.55	.00	.00	T.	.00	.00	4.02
1899-1900	.00	.00	1.96	.55	1.06	.00	------	------	------	------	------	------	------
Mean	------	------	------	------	------	------	------	------	------	------	------	------	10.51

T indicates trace.

CROPS.

The distinctive crop of San Bernardino Valley is citrus fruits. Oranges predominate, followed next by lemons, and of late years the grape fruit has become a popular product. The favorite variety of orange is the navel, a seedless fruit which has been highly developed at Riverside. Other varieties are the Mediterranean Sweet, the St. Michael, and the Malta Blood. These all are budded fruits on seedling roots. Pl. III, *A*, shows a bearing grove of navel oranges at Riverside. The seedling orange that was at first planted extensively is not now popular. Its value is less than half that of the budded fruit. The seedling tree is larger and longer lived than the budded varieties, but the fruit is not so sweet nor so highly flavored. The Eureka and Lisbon are the favorite varieties of lemon. The orange trees bloom in March and the crop ripens from December 1 to May 1. Some varieties of lemon trees are constantly ripening fruit, a heavier crop being borne in the winter. Olives, almonds, prunes, apricots, peaches, pears, and wine, raisin, and table grapes are all grown in this

A. NAVEL ORANGE GROVE AT RIVERSIDE, SAN BERNARDINO VALLEY.

B MAGNOLIA AVENUE, RIVERSIDE.

district to perfection and in large quantities. Generally speaking, these are planted where the frost line debars the growth of citrus fruits. The citrus trees being constantly in fruit or blossom require more water than deciduous trees; therefore where the water supply is limited deciduous fruits are the more popular crop.

In the moist lands of the river bottoms near San Bernardino dairy farming is generally practiced, the products being disposed of to the orchardists and the local towns. In the moist lands near the lower narrows of the river beets are grown without irrigation, and at Chino there is a beet-sugar factory. The beets grown here contain from 16 to 18 per cent of saccharine matter, which is very high compared with those grown in Eastern localities.

An interesting feature of this district is the care that is taken of the orchards. No weeds are permitted to grow, and the lands are evenly sloped to true grades. Efforts are made to carry out artistic and neat effects in the homes, the streets, the canals, and the groves, as will be seen in Pls. III, *B*, and IV.

In the eleven years prior to 1898 Riverside shipped nearly 7,000,000 boxes of oranges, which at fair figures means an average income of $1,000,000 a year. With the present condition of the orchards an income twice as large may fairly be expected. There were 4,000 carloads of citrus fruits shipped from Riverside during the season of 1897–98. The annual yield there in 1899 is said to be about one-third of the entire output of the State. Navel oranges during the last ten years (1890–1900) have averaged at Riverside $1.50 a box,[a] and Mediterranean Sweets $1.25 to $1.50 a box; Malta Bloods and St. Michaels have brought somewhat higher prices. The production of the lemon has not been very popular in the past, as the method of curing it was not well understood. This problem has now been mastered, however, and the well-cured California lemon ranks with the best Sicilian product. The United States imports $5,000,000 worth of lemons yearly, and California is after the market. Lemons are worth about $1 a box, and the yield of trees fifteen years old is from five to eight boxes each.

It is difficult to say what the profits of citrus fruit culture are. It is a question of the survival of the fittest. The man whose crop is frozen every third year, or who has but half a water supply in dry years, or whose trees are of a low grade, is not among the fittest. For financial success these conditions must be relatively perfect. With these conditions satisfactory he should average 10 per cent net on his investment at the end of fifteen years. In the past, when prices were higher and competition less severe, there doubtless have been many cases where as much as $500 or $1,000 per acre per season has been produced from an orchard, and it is possible that these figures may again be reached, but they are not a proper basis for estimates. It costs in the neighborhood of $900 an acre to get a citrus orchard in bearing condition, including land, water, and interest on the invest-

[a] Prices are f. o. b. cars.

ment. Under favorable conditions a ten-year-old orchard should produce $200 gross and $100 net per acre. Almost without exception the policy of living in the Eastern States and paying kind friends or parental corporations to attend to an orchard results in the loss of money and mutual respect. Under the best conditions it takes five or more years of hard, patient, and intelligent work to get an orange orchard on a paying basis. It is not a poor man's business. When success comes it is an ideal life to spend one's days among the golden fruit in a pleasant land. It is a country life surrounded by cultivated neighbors and with most of the conveniences of the city.

In the Eleventh Census (1890), under Agriculture by Irrigation, page 33, is the following statement:

> In average value on June 1st, 1890, of farm land irrigated, $150 per acre, California leads the list, Utah coming second, with $84.25 per acre. This figure exhibits perhaps better than any other the extraordinary values of land in California arising from its utilization for orchards and vineyards. The value of these ranges from $300 to $500 and upward per acre, thus greatly raising the average value of irrigated land, which of course also includes the great areas devoted to the raising of hay crops. The same fact is exhibited, though perhaps not as clearly, in the high average value of products per acre in 1889 and in the large average first cost of water rights, $12.95 per acre, and average value of these in 1890, $39.28 per acre, a high cost and value being justified by the enormous profits resulting from successful fruit culture. In short, it may be said that the conditions in California, although by no means perfect, have produced such results that they have served to stimulate development in all parts of western United States. Much is still to be accomplished by the subdivision of the great irrigated holdings, this state standing first in the aggregate area and average size of irrigated holdings of over 160 acres in area. These, although embracing 61.88 per cent of the total area irrigated are not of as great relative importance as in Nevada and Wyoming, where the large farms are devoted mainly to the forage crops.

What is true of the State as a whole is doubly true of San Bernardino Valley. There irrigation and horticulture have probably reached higher planes of development than in any other irrigation district.

During the season of 1900–1901 southern California shipped 7,664,626 boxes of oranges and 908,856 boxes of lemons, worth to the growers $5,750,000.

Pl. IV, *A*, is a view of an orange grove in San Bernardino, showing a method of irrigating by throwing up the earth so as to construct around each tree a basin in which water is turned and allowed to stand until absorbed. Pl. IV, *B*, shows an irrigation canal of the Riverside Water Company near Riverside.

WATER SUPPLY.

The rain clouds from the Pacific Ocean, passing in large part over the lower intervening foothills and valleys, are condensed on being forced up and over the high crest of the Sierra Madre and the San Bernardino Mountains, which are from 6,000 to 11,000 feet in elevation.

The precipitation in the mountains occurring in the winter months

A. ORANGE GROVE, SHOWING METHOD OF BASIN IRRIGATION.

B. CANAL OF RIVERSIDE WATER COMPANY NEAR RIVERSIDE.

is largely in the form of snow, part of which does not melt until the spring months, thus maintaining the flow of the streams up to the first of May at a relatively large volume. Occasional thunderstorms visit the higher mountains in the summer. They are very violent and cause a sudden rise of the streams, which is not maintained. The rainfall of the valleys is about 15 inches annually, occurring in nongrowing months, there being little or no precipitation from April 1 to November 1. The grades of the drainage lines in the mountains are very steep, affording little opportunity for storage reservoirs. This is particularly unfortunate, as more than three-fifths of the stream flow occurs during the winter months. The Bear Valley reservoir is the one exception. It has a capacity at the 60-foot contour of 40,476 acre-feet, or 5,590 miners' inches (111.8 second-feet), flowing for six months. This water is taken to the Redlands and Highlands districts. The works are described in the Nineteenth Annual Report of the United States Geological Survey, Part IV, pages 584 to 598.

With the exception of San Timoteo and Temescal creeks all of the valley streams rise in the Sierra Madre and supply more than 90 per cent of the water used in the valley. There are threo classes of water supply available, viz, surface streams, underground water, and water held in storage reservoirs. The principal stream of southern California is Santa Ana River. From the mouth of its mountain canyon to a point 4 miles east of Colton it has a grade of 100 feet to the mile, while below that point, to the lower narrows, the grade is but 27 feet to the mile. City Creek has a grade for the first 5 miles below its canyon of 100 feet to the mile, Lytle Creek a grade of 150 feet, and San Antonio and Cucamonga creeks a grade of 200 feet. The grades of these streams are still heavier in their granitic mountain canyons, and during flood stages they have carried down masses of sand and bowlders and built delta-like benches or mesas far out into the center of the valley, the finer material being conveyed farthest. In this way the valley has been filled to a depth of several hundred feet. In their course over these deltas the winter floods largely disappear in the detritus near the rim and penetrate in part under these layers of clay, thus forming reservoirs of ground water of unknown but great capacity. The water diverted for irrigation at the mouths of the canyons is also distributed upon porous soils, on steep grades, and with other underground bodies of water gravitates on the heavy prevailing slopes toward the center of the valley. One and a half miles northeast of Colton is an outcropping of clay known as Bunker Hill. This is a point on a low clay ridge bearing approximately S. 40° E., connecting with the foothills on the south side of the valley east of and near the mouth of Reche Canyon and extending northwest along the west bank of Lytle Creek. This ridge is the lower limit of the upper Santa Ana artesian belt. It also serves to

force to the surface the return waters from irrigation that are flowing or percolating westward above the clay cap. Six-sevenths of the water of Riverside is obtained from underground sources above this range of clay hills. This ridge was probably formed by the folding of the floor of the valley.

A somewhat similar condition is repeated south of Chino, at Rincon, where Santa Ana River has cut its way through the lower Coast Range. At this point the underground waters from Cucamonga, San Antonio, and Temescal creeks as well as the return waters from irrigation near Pomona, Ontario, Corona, and Riverside are forced to the surface, creating wet lands and rendering a water supply available for Anaheim, Santa Ana, and Fullerton. Beyond these lower narrows there is an open plain to the sea, and the Santa Ana makes no further reappearance, except in an artesian district below the 100-foot contour. A view of the river below Rincon is shown in Pl. V, *A*, and a view of the division box of the Santa Ana and Anaheim canals, which divert water from the river below Rincon, in Pl. V, *B*.

This artesian and percolating water yields a very uniform flow. The development works near Colton and San Bernardino draw from this reservoir as a spigot draws from a tank. The flow is relatively uniform, and the tank is filled by winter floods and by seepage. The greater portion of the hydrostatic pressure is exhausted in overcoming the large amount of friction expended by the water in passing through the sand, and its flow comes largely under the law of hydraulics. The capping or uncapping of numerous wells in a neighborhood has little immediate effect on the flow of any well until the full discharge capacity of the underground conduit is approached. When that occurs the water in all of the wells is lowered and pumping must be resorted to. Pl. VI (*A* and *B*) shows a group of artesian wells of the Riverside Water Company near Colton, in the Santa Ana River bottoms. In the foreground of Pl. VI, *B*, is shown an aerating basin.

The velocity of underground flow is extremely difficult to compute. It has been discussed at length by Professor King and Professor Slichter, of Madison, Wis.,[a] and by Prof. L. G. Carpenter, of Fort Collins, Colo.[b] A great deal depends upon the size of the particles composing the soil and the way in which they are mixed. Cobbles, coarse sand, and sandy soil mixed in equal parts is more impervious than any one of the materials singly. Water percolating under ground for long periods often establishes underground channels from an eighth of an inch to 10 inches in diameter, then ceases to percolate and begins to flow through them. These conditions tend to confuse, because most of the formulas that have been presented are based on soil grains of distinct sizes.

[a] Nineteenth Ann. Rept. U. S. Geol. Survey, Pt. II.
[b] Bulletin No. 83 of Colorado experiment station, Fort Collins, Colo.

A SANTA ANA RIVER BELOW RINCON.

B. DIVISION BOX OF SANTA ANA AND ANAHEIM CANALS BELOW RINCON.

A. ARTESIAN WELLS OF RIVERSIDE WATER COMPANY.

B. ARTESIAN WELLS AND AERATING BASIN OF RIVERSIDE WATER COMPANY.

The flat valley area above Colton comprises 132 square miles, and it is reasonable to estimate that 100 square miles of this consists of gravel deposits eroded from the mountains. These gravels are of unknown but great depths. Numerous wells have been put down to a depth of 900 feet, and the writer does not know of bed rock being encountered. If this gravel bed is considered to have an average depth of 300 feet and the voids or interstices therein are taken at 33 per cent, the aggregate storage capacity would be 6,400,000 acre-feet. It is believed to be greater instead of less than this amount. As the water plane is drawn down throughout this mass its capacity to absorb subsequent floods at its rim, where the mountain streams debouch, is increased. It is a great regulating reservoir, sufficient in capacity to carry the irrigation communities through cycles of dry years, to be recharged during those of copious rainfall. The observations of the elevation of this water plane will be of value in making comparisons at a later date to determine whether the present rate of withdrawal is permanently lowering it or if in wet years the rainfall is sufficient to recharge the reservoir and restore it to its former level. This subject is of vital interest to the irrigators of the valley. From data now available a continuous withdrawal of 140 second-feet is believed to be reasonably safe.

The water of Warm Creek and of the artesian wells of the Gage system has been analyzed by Prof. E. W. Hilgard, of the University of California, with the following results:

Analyses of waters from artesian wells of the Gage system and from Warm Creek.

[Composition in 10,000 parts.]

	Artesian wells.		Warm Creek at mill.		Artesian wells.		Warm Creek at mill.
	Group D, No. 5.	Group A, No. 2.			Group D, No. 5.	Group A, No. 2.	
	Per ct.	*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*	*Per ct.*
Total residue	1.911	2.266	2.604	Calcium carbonate	1.017	1.212	0.762
Soluble part	.418	.418	1.119	Magnesium carbonate	.232	.249	.253
Sodium chloride (common salt)	.063	.091	.257	Silica	.244	.239	.324
Sodium sulphate (glauber salt)	.193	.313	.582	Summary, in grains per gallon:			
Sodium carbonate (soda)	.102	.021	.200	Total residue	11.16	13.23	15.21
Potassium sulphate	.060	.068	.080	Soluble part	2.44	2.84	6.53
Insoluble after evaporation	1.493	1.778	1.485	Insoluble after evaporation	8.72	10.38	9.67
Calcium sulphate	.....	.078	.146				

In total solids this water compares favorably with that of Los Angeles and Kern rivers, and is much purer than the water of the coast streams. It carries large quantities of potash salts, and not enough calcium carbonate to injure the well-drained lands of the Riverside mesa.

SMALL CANALS NEAR COLTON AND SAN BERNARDINO.*

DESCRIPTIONS.

Haws & Talmage ditch.—This ditch receives its supply from the rising water of Warm Creek, and is the first diversion on that stream between Harlem and Rabel Springs. It is a small earthen ditch, and takes water from the south side or left bank of the creek, and distributes it southwest of Harlem Springs. The diversion is by means of a dam. The ditch is three-fourths of a mile long. It is owned and maintained by local ranchers, and is entitled to 50 miners' inches (1 second-foot) of water. Usually the ditch is cleaned each spring, or whenever it becomes so foul that some irrigator can not get as much water as he requires. The water is used for alfalfa and other dairy products. The cost of maintenance of ditches of this class is from 50 cents to $1 per acre per year. The supply is relatively constant. The ditch was built in 1857, separating its water right from that of the Rabel Dam ditch. During the years 1898 and 1899 this ditch was practically dry, the only water it received being that pumped from the Harlem swimming pool, which is cleaned about twice a week. In June and August, 1899, and in March, 1900 and 1901, the ditch was dry.

Rabel Dam ditch diverts its water by means of an earthen dam at lot 2, block 60, San Bernardino Rancho, on Warm Creek. It is the second ditch on that stream. As is the case with all of these rising waters, the supply is practically constant throughout the year. An agreement, made in October, 1895, between the Riverside Water Company and the owners of the ditch provided for the natural flow of water in Warm Creek at the head of the ditch to the amount of 250 miners' inches, and in the agreement it was stipulated that the Riverside Water Company should at its own expense build at the head of the ditch an iron weir embedded in a cement foundation, to measure the water. This was done. The canal is an earthen ditch 4.2 miles in length, and has a capacity of 250 miners' inches (5.0 second-feet). It takes its water from the south side of Warm Creek and carries it to the southwest of Harlem Springs, irrigating 400 acres of alfalfa, vegetables, and garden produce. It is owned and operated by local ranchers. It was built in 1854 by the Mormon settlers, and is the oldest water right on Warm Creek. On June 20, 1898, it was discharging 5.37 second-feet. During the summer of 1899 the iron weir at the head of the ditch was removed by the owners of the ditch, with the consent of the Riverside Water Company. The upper part of the ditch was lowered by running it on a flatter gradient to the headworks, with the idea of diverting Warm Creek at a lower level. This plan increased the flow of water for a time, but it soon dropped to less than the original flow.

Shay or Stout Dam ditch.—The headworks of this ditch are in the west half of lot 4, block 60, San Bernardino Rancho, 1 mile north and 3 miles east of the city of San Bernardino. The diversion is by means of an earthen dam. The supply is relatively constant. The canal is 1½ miles in length; it runs west on the north side of the San Bernardino base line and Warm Creek, and irrigates those lands. The ditch is used the year round, and is cleaned twice a year. The cost of maintenance to consumers is less that $1 per acre per year. It served 210 acres in 1885 and 150 acres in 1898. It was built in 1857, and ranks third in its order of water rights to Warm Creek. By a compromise made with the Riverside Water Company in 1895 this ditch is entitled to 112.5 miners' inches of water (2.25 second-feet), provided there is that amount in Warm Creek at the headworks. During the years 1899 and 1900, however, the supply fell considerably below that quantity.

McKenzie ditch.—The headworks, consisting of a wooden dam, are on Warm Creek, the center of lot 8, block 51, San Bernardino Rancho, 2 miles east of the city of San Bernardino. The supply is relatively constant. The ditch was built

*The writer is indebted to Mr. Kingsbury Sanborn for most of the data regarding these canals.

in 1862. It irrigates lands immediately east of San Bernardino, between City and Warm creeks, and 85 acres on the south side of City Creek. The canal is about 1.3 miles in length. It is an earthen ditch built in sandy loam, with a flat grade, and is owned and operated by local ranchers. It is said to lose 33 per cent of its volume by seepage. The owners claim all of the water of Warm Creek at the point of diversion, but the Riverside Water Company claims that their right is limited to the original capacity of the ditch, which was 100 miners' inches (2.0 second-feet). The ditch is still in litigation. It has lately been enlarged. Three hundred acres of alfalfa and gardens are irrigated. Cost of maintenance is prorated and amounts to about 50 cents per acre per year. On June 20, 1898, it was discharging 127 miners' inches (2.54 second-feet).

Meeks & Daley ditch.—This ditch originally diverted its water from the lower part of Warm Creek, and the Agua Mansa, Juaramillo, and San Salvador canals took water from Santa Ana River, southeast of Colton. The owners of these four canals, in cleaning them out each year, gradually enlarged their sections, to the detriment of the Riverside Water Company, which company instituted suit against them to restrict their diversion. To avoid a protracted lawsuit and excessive loss of water by seepage in sandy channels, a compromise was arranged in 1885 by which the Riverside Water Company agreed to build and deliver to the owners of these ditches a cement-lined canal, estimated to cost $30,000, which should deliver from this conduit, at certain stated points, the following amounts of water:

Ditches to be supplied by cement-lined canal.

Name of ditch.	Original source of supply.	Water guaranteed.
		Miners' inches.
Meeks & Daley	Warm Creek	400
Juaramillo	Santa Ana River	50
Agua Mansa	do	250
San Salvador	do	125
Loss by evaporation (estimated)		25
Total		850

This canal was built by the Riverside Water Company at a cost of $37,281. All water remaining available from the sources of these canals belongs to that company. In 1885 the Meeks & Daley Water Company was incorporated, with a capital stock of $78,000 divided into 780 shares. to handle these combined waters.

The headworks of the new canal were located 1½ miles northeast of the town of Colton and a half mile east of Bunker Hill. The headworks of the Meeks & Daley ditch consist of a well-constructed brush dam across Warm Creek, which diverts the water to a weir at the head of the ditch. At the weir the ditch is 10 feet wide on the bottom and 1½ feet deep, with side slopes of 1½ to 1, gradually contracting to its normal size at station 28, which is 3 feet wide on the bottom, 5 feet wide across the top, and 2 feet deep. The sides are of rubble masonry, with a 3-inch concrete bottom, and the whole inside is plastered with cement mortar a half inch thick. The supply is from Warm Creek and is very constant in volume. Under this contract the Riverside Water Company made a saving of from 100 to 200 miners' inches (2 to 4 second-feet). The canal built by them is about 3½ miles in length. It runs through the southern side of the town of Colton and around the south side of Slover Mountain, being on the north or right bank of Warm Creek and Santa Ana River. It is owned by a stock company of local ranchers, each share of the stock carrying with it a water right to some certain piece of land to which it is appurtenant. The water is used largely for the irrigation of citrus fruits.

The Agua Mansa ditch is an extension of the Meeks & Daley ditch through the Agua Mansa and San Salvador districts. It is of the same construction as the Meeks & Daley ditch, but is smaller, being 2 feet on the bottom and from 1 foot to 1½ feet deep, according to the grade, with side slopes of ½ to 1. Very little of the original Agua Mansa land is now irrigated, as the irrigation on the mesa has converted the land into a bog hole, unfit for cultivation, and many shares of water have been sold to ranchers in West Riverside, who now own the controlling interest and are using the water on their lands.

Beam ditch derives its water from a cienaga tributary of Warm Creek in lot 14, block 43, San Bernardino Rancho. The ditch is about a mile in length. The water is diverted by means of a brush dam, and flows in a southwesterly direction, irrigating the land lying west of Warm Creek, in blocks 43 and 44 of the San Bernardino Rancho. The ditch has an apparent capacity of 45 miners' inches, and irrigates about 100 acres of land. On June 20, 1898, it was flowing 0.67 second-foot in the flume near the headworks.

Timber ditch.—This was one of the first canals constructed in San Bernardino Valley. It diverted its water from Santa Ana River near the center of sec. 8, T. 1 S., R. 3 W. The water rights of this canal were transferred by individual owners to the North and South Fork canals of Highlands and Redlands, and at the present time it is practically abandoned. The water was applied to the lands between the city of San Bernardino and Santa Ana River. It was entirely dry during the summers of 1898 and 1899. At its headworks there is a flume intake 4.3 feet wide and 2 feet deep, also a crib diversion dam. This ditch is described in the Nineteenth Annual Report of the United States Geological Survey, Part IV.

Logsdon & Farrell or Waterman ditch.—The Logsdon & Farrell ditch makes its diversion from the south side of City Creek, a mile east of the city of San Bernardino, by means of a flume 2 feet wide and 1 foot deep and a rough sheet-pile dam. The canal is three-fourths of a mile in length, and its water is used southeast of the city. About 80 acres of gardens are irrigated. On June 29, 1898, there was flowing in this ditch 36 miners' inches (0.72 second-foot) of water. This ditch is a combination of the Waterman, Logsdon-Farrell, and Brooks ditches.

Whitlock ditch.—This ditch takes its water from the north bank of City Creek 2 miles east of the business portion of the city of San Bernardino, and is about a half mile in length. At the place of measurement it is a flume 1.5 feet wide and 0.8 foot deep, and on June 29, 1898, it was discharging 12 miners' inches, or 0.24 second-foot. Its water is used to wash vegetables, and it is mingled with the waters of the McKenzie ditch and used on Chinese vegetable gardens.

Daley ditch.—This ditch diverts water three-fourths of a mile east of the business portion of the city of San Bernardino and about one-fourth of a mile east of the junction of Warm and City creeks, from the north side of the latter creek, crosses to the south side of that creek, and distributes its water on 40 acres of block 6 of the San Bernardino Rancho. It is about a half mile in length. The flume crossing City Creek is 1 foot wide and 1 foot deep. On June 29, 1898, it was carrying 31 miners' inches (0.62 second-foot).

McIntyre ditch.—This canal makes its diversion from the south or right bank of Lytle Creek, near the southwest corner of the city of San Bernardino, and receives its supply from the return water of that creek. It is approximately 1 mile in length, and distributes its water on the south side of Lytle Creek, between Colton avenue and Mount Vernon avenue. It is an eight-day ditch, and is owned by local ranchers, who maintain it for about 70 cents per acre per year. About 30 acres are irrigated for alfalfa. During the years 1898, 1899, 1900, and 1901 the ditch was dry.

Whiting ditch also derives its supply from the return water of Lytle Creek, and distributes it on the adjoining lands of D. G. Whiting, who owns the ditch. On June 27, 1898, it was carrying 15 miners' inches (0.30 second-foot). Twenty-five acres of pasture are irrigated.

Furguson water.—This is a 2½-miners' inch right in Ranchero ditch, which comes from Raynor Springs. The water is used around Bloomington.

Ward & Warren ditch.—This is one of the oldest ditches on Santa Ana River, and is the outgrowth of the Warren-Warner ditch, the Jansen ditch, and the waste water from the Hunt & Cooley ditch. The ditch originally took its water from Santa Ana River near the east end of the Southern Pacific Railway bridge, in lot 8, block 64, San Bernardino Rancho, but during the flood of 1892 the main channel of Santa Ana River was changed to a point about a half mile to the north, and the following spring the Ward & Warren ditch was extended to the new channel of the river. The water is now diverted by means of a rough sand and brush dam in the westerly part of lot 2, block 64, San Bernardino Rancho.

During the years 1888 and 1889 this ditch was considerably enlarged and the water spread over a greater area. The Riverside Water Company, which had been using the water of Santa Ana River for years, brought suit against the owners of the ditch, to restrain them from using all the water in Santa Ana River at their headworks, claiming that they were entitled to only the original capacity of the ditch.

The case came to trial February 26, 1890, the decision being that the owners of the ditch are entitled to the water flowing from Santa Ana River at the head of the Ward & Warren ditch to the extent of 309 miners' inches (6.18 second-feet), measured under a 4-inch pressure, the measurement to be made from the center of the orifice, and that the Riverside Water Company is the owner and entitled to the use of the remainder of the water flowing in Santa Ana River at the head of the Ward & Warren ditch. The court further decreed that the owners of the Ward & Warren ditch are entitled to have from the Rice & Thorne tracts (which are owned by the Riverside Water Company) on Santa Ana River water to the amount of 78.18 miners' inches (1.56 second-feet), measured under a 4-inch pressure from the center of the orifice, when necessary to make up the 309 miners' inches. This 78.18 miners' inches was the overflow from the fish pond of a cienaga located on their lands, the stream of which is one of the natural tributaries of Santa Ana River. This pond, owing to the dry season and the development of artesian water in that neighborhood, is now almost dry, and the 78.18 miners' inches delivered to the Ward & Warren ditch is now practically all artesian water. The line of the ditch is located through the dry and sandy bed of Santa Ana River and loses a large percentage of its water before reaching the first point of distribution. In June, 1898, this ditch was receiving from the Rice-Thorne canal 1.60 second-feet of water and from Santa Ana River 0.72 second-foot.

North Riverside or Jurupa canal.—The Jurupa canal, sometimes called the North Riverside, derives its water from different sources: (1) From a covered flume in the Santa Ana River bottom, in lot 3, block 88, San Bernardino Rancho, above Colton avenue crossing; (2) from surface development in two cienagas in lot 2, block 88, San Bernardino Rancho; and (3) from the Salazar water. The Salazar water was originally diverted from the bed of Santa Ana River.

The Riverside Water Company agreed, because of the priority of the Salazar right, to permit the water for this ditch, to the extent of 75 to 100 miners' inches (1.5 to 2 second-feet), to pass its headworks and be conveyed by a sandy river bed to the Salazar headworks. In order to prevent the loss by seepage and evaporation in the river bed, the Riverside Water Company now delivers into the Jurupa flume 75 miners' inches (1.5 second-feet), in consideration for which it diverts all of the water at the headworks of its canal. All of these developments occur east of the Colton avenue crossing of Santa Ana River. The ditch which is now called the Rubidoux ditch is generally known as the Jurupa ditch, and diverts its water from Santa Ana River just north of the point where the county line between Riverside and San Bernardino crosses the lands of the Rubidoux ranch. The ditch now known as the Jurupa, belonging to the North Riverside Land

and Water Company, diverts a portion of its water from an underground flume in the bed of Santa Ana River a short distance east of the Colton avenue bridge. On July 1, 1898, the canal was flowing 7.11 second-feet at the Colton avenue crossing. This includes the 75 miners' inches (1.50 second-feet) of Salazar water. The main canal is 17 miles in length. The company owns the land upon which the water is distributed, and claims the right to develop all the water available at its headworks. The first 350 miners' inches (7 second-feet) belong to settlers to whom the company had sold water and land. The Jurupa ditch carries 75 miners' inches from the Riverside Water Company's flume, and this water is known as the Salazar right. It is measured at the junction of the Riverside Water Company's flume with the North Riverside and Jurupa canal. Agua Mansa water enters the Jurupa canal from the Meeks & Daley ditch 1 mile southwest of Slover Mountain, and is carried by it to the San Salvador district. The Temescal tin mine syndicate has a run of 200 miners' inches (4 second-feet) for twenty-four hours every eighth day through the Jurupa ditch. Ordinarily the Jurupa ditch contains—

	Miners' inches.	Second-feet.
Agua Mansa water	350	(7.0)
Salazar water	75	(1.5)
Santa Ana River water	350	(7.0)
Total	775	(15.5)

The following measurements have been made:

	Miners' inches.	Second-feet.
July 1, 1898, Jurupa flume at Colton avenue	355	(7.11)
June 18, 1898, Jurupa flume below Agua Mansa junction, including Agua Mansa water	691	(13.83)
August 27, 1898, Jurupa flume at Colton avenue, below Agua Mansa junction, including Agua Mansa water	509	(10.18)

During the year 1897 the assessments to the owners of the Jurupa ditch amounted to $9.54 per miners' inch. They charge $3.27 per inch per year for carrying Agua Mansa and other water.

The canal is located around a rock hill immediately above the old upper canal of the Riverside Water Company and crosses the river in a flume on a trestle 2,460 feet in length, shown in Pl. VII, *B*. Then for 2 miles the water is flumed along a bluff on the north bank of the river, after which it passes through a tunnel 4,000 feet long into an open ditch 3 miles long, and thence to the Jurupa mesa lands. The Jurupa Land and Water Company was incorporated in May, 1888, with a capital stock of $3,500,000, divided into $100 shares.

Hunt & Cooley or Camp Carlton ditch.—This was originally one of the oldest diversions on middle Santa Ana River. It was taken out in 1859, and had several headings in the river, which were washed out by floods, until the final one was made at about the point where the Gage canal started to divert its water, and it remained there until the year 1887, when the managers of the Gage canal agreed with the owners of the ditch to bore wells and develop for them 130 miners' inches of water, and to receive in return what they thought to be the right to all the water flowing in Santa Ana River at the headworks of this ditch. This led to a long and expensive lawsuit with the Riverside Water Company, who contended that the Gage canal was entitled to only an amount of water equal to the original capacity of the canal, which was 200 miners' inches. It resulted, however, in the courts allowing the Gage canal the right to 298.5 miners' inches of the flow of Santa Ana River at the headworks of their canal.

A. FLOWING WELLS OF GAGE CANAL SYSTEM, VALLEY OF SANTA ANA RIVER.

B. FLUME AND INVERTED SIPHON OF JURUPA CANAL.

DISCHARGE MEASUREMENTS.*

Haws & Talmage ditch.—On June 7, 1898, 0.84 second-foot was flowing in this ditch near the headworks. The area of the water section was 0.9 square foot, the surface velocity 1.33 feet per second. Measurements were made by floats. Coefficient 70 per cent.

September 14, 1898, all of the water in Warm Creek at the head of the ditch was passed through the waste gate; by weir it measured 0.43 second-foot. The weir was 4.6 feet long, the head 0.094 foot, two full contractions, velocity of approach less than 0.5 foot per second.

March 2, 1899, a weir was put in near the head of the ditch, and the discharge measured 0.28 second-foot; length of weir 1 foot, head 0.2 foot, velocity of approach less than 0.5 foot per second, two full contractions.

In June and August, 1899, and in March and on June 12, 1900, the ditch was dry.

Rabel Dam ditch.—September 14, 1898, at 2.10 p. m., this ditch was diverting 3.07 second-feet over the iron weir at the headworks, which was all of the water in Warm Creek at that point. The weir is 4 feet long, the head was 0.38 foot, two full contractions, velocity of approach less than 1 foot per second.

March 2, 1899, the ditch was discharging 2.36 second-feet at the head; length of weir 4 feet, head 0.31 foot, velocity of approach less than 1 foot per second, two full end contractions. This was all of the water in Warm Creek at the point of diversion.

June 16, 1899, at 1.45 p. m., this ditch was discharging 1.54 second-feet; head 0.24 foot, length of weir 4 feet, two full end contractions, velocity of approach less than 0.5 foot per second.

During the summer of 1899 the iron weir at the head of the ditch was removed by the owners of the ditch, with the consent of the Riverside Water Company. The upper part of the ditch was lowered by running on a flatter gradient to the headworks, with the idea of diverting Warm Creek at a lower level. This plan increased the flow of water for a time, but it soon dropped to less than the original flow.

August 25, 1899, the discharge measured 0.94 second-foot; the water area was 0.9 square foot, the surface velocity 1.5 feet per second.

March 15, 1900, the 4-foot iron weir was again in place; the discharge measured 0.54 second-foot, the head was 0.12 foot, and there was no perceptible velocity of approach.

June 12, 1900, at 12 m., the discharge measured 0.35 second-foot at the headworks weir; length of weir 4 feet, head 0.09 foot, velocity of approach less than 0.5 foot per second, two full end contractions.

Shay or Stout Dam ditch.—On June 20, 1898, the volume in this canal measured 2.30 second-feet; length of weir 2 feet, head 0.502 foot, velocity of approach 0.7 foot per second, two end contractions.

September 14, 1898, at 1.55 p. m., the discharge over the same weir was 2.08 second-feet. Being at the end of the irrigating season the ditch had not been cleaned and was very foul. The tail water was higher than the crest of the weir by 0.193 foot, causing the weir to be submerged. Head 0.5 foot, two end contractions, velocity of approach less than 0.5 foot per second. Fteley and Stearns's formula was used.

March 2, 1899, the discharge over the same weir was 2.23 second-feet; head 0.5 foot, two end contractions, velocity of approach less than 0.5 foot per second.

June 16, 1899, at 2.10 p. m., the discharge was 1.13 second-feet. The ditch was again foul, and the weir was submerged 0.320 foot; head 0.406 foot, velocity of approach less than 1 foot per second.

* All measurements were made by Mr. Kingsbury Sanborn, of Riverside, except where stated to the contrary.

August 25, 1899, at 2.15 p. m., the discharge measured 0.9 second-foot, head 0.27 foot, two end contractions, velocity of approach less than 0.5 foot per second.

A few months previous to March 15, 1900, when a measurement was made, the owners of the Shay ditch relocated the ditch, starting from the headworks and taking it to higher grounds, which caused the water to back entirely over the weir, so that it became necessary to make a float measurement. The water area was 1.45 square feet, surface velocity 0.5 foot per second, discharge 0.507 second-foot, coefficient 70 per cent.

On June 19, 1900, at 1.10 p. m., the discharge was 0.4 second-foot about 200 feet below the dam across Warm Creek; sectional area 1.7 square feet, surface velocity 0.34 foot per second, coefficient 70 per cent.

McKenzie ditch.—On June 20, 1898, a float measurement was made. The area of the section was 2.90 square feet, surface velocity 1.25 feet per second, coefficient 70 per cent, discharge 2.54 second-feet.

September 12, 1898, at 2.30 p. m., the discharge a half mile below the headworks measured 2.08 second-feet. The sectional area was 5.2 square feet, the velocity of approach 0.64 foot per second, coefficient 70 per cent.

March 2, 1899, the discharge measured 9.4 second-feet at the same point as the last measurement; the sectional area was 4.9 square feet, surface velocity 2.77 feet per second, coefficient 70 per cent.

June 16, 1899, at 2.45 p. m., the discharge measured 3.86 second-feet about 150 feet below the headworks on Warm Creek; the sectional area was 1.9 square feet, surface velocity 2 feet per second, coefficient 70 per cent.

August 22, 1899, there was flowing in the ditch at the same point as the last measurement 2 second-feet; the sectional area was 4.1 square feet, the surface velocity 0.7 foot per second, coefficient 70 per cent.

March 16, 1900, the discharge measured 2.3 second-feet about 250 feet below the headworks on Warm Creek; the sectional area was 3.3 square feet, the surface velocity 1 foot per second, coefficient 70 per cent.

June 19, 1900, at 1.10 p. m., the discharge measured 1.57 second-feet about 150 feet below the headworks dam; the sectional area was 2.2 square feet, the surface velocity 1 foot per second, coefficient 70 per cent.

Meeks & Daley ditch.—Measured on June 20, 1898, the discharge at the headworks weir was 8.42 second-feet (421 miners' inches); length of weir 6 feet, head 0.525 foot, two end contractions, velocity of approach less than 0.5 foot per second.

Measured on March 2, 1899, at the headworks weir the discharge was 17 second-feet; length of weir 6 feet, head 0.917 foot, two end contractions, velocity of approach less than 1 foot per second.

June 26, 1899, the discharge at the headworks weir was 15.48 second-feet, the head 0.845 foot, two end contractions.

August 25, 1899, the discharge at the headworks weir was 10.45 second-feet, head 0.659 foot.

March 1, 1900, the weir was submerged 0.28 foot; the discharge was 13.94 second-feet; length of weir 6 feet, head 0.84 foot, velocity of approach less than 1 foot per second.

June 19, 1900, at 4 p. m., the discharge measured 13.78 second-feet at the headworks weir, which was submerged 0.415 foot; the velocity of approach was less than 1 foot per second, length of weir 6 feet, head 0.875 foot, two end contractions.

Logsdon & Farrell ditch.—Measured near headworks on June 29, 1898, by J. B. Lippincott and K. Sanborn. Area of section 0.878 square foot, mean velocity 0.824 foot per second, coefficient 80 per cent, discharge 0.72 second-foot.

In September, 1898, the discharge was 0.63 second-foot at the same place.

March 1, 1899, 1.61 second-feet of water was in the flume near the headworks. This ditch is flat, and it is impossible to put in a weir without losing a large percentage of the water, so that it became necessary to make float measurements. The width of the flume is 2 feet, the depth of the water 0.7 foot, sectional area

1.41 square feet, surface velocity 1.43 feet per second, coefficient 80 per cent. The flume was in fair condition.

June 27, 1899, the discharge measured 1.15 second-feet at the same place; depth of water 0.71 foot, surface velocity 1 foot per second, sectional area 1.44 square feet, coefficient 80 per cent.

August 25, 1899, the discharge measured 0.54 second-foot in the flume near the headworks, which was in fair condition. The depth of water was 0.56 foot, surface velocity 0.6 foot per second, sectional area 1.12 square feet, coefficient 80 per cent.

March 15, 1900, the discharge measured 1.26 second-feet at the same place. There was a deposit of sand in the bottom of the flume, and the depth of water was as follows: Side 0.82 foot, center 0.86 foot, and opposite side of flume 0.84 foot. The surface velocity was 1 foot per second, coefficient 75 per cent.

June 23, 1900, the discharge measured 0.49 second-foot in the ditch near the headworks dam; sectional area 0.9 square foot, surface velocity 0.77 foot per second, coefficient 70 per cent.

Beam ditch.—Measured June 30, 1898, 300 feet below headworks, by floats. Area of section 1.08 square feet, mean velocity 0.63 foot per second, discharge 0.67 second-foot.

March 2, 1899, discharge measured 0.72 second-foot in the flume near the headworks. This ditch is very flat, and it is impossible to put in a weir and get satisfactory results; for that reason float measurement was made. The water area was 1.5 square feet, the surface velocity 0.6 foot per second. The flume was in fairly good condition. Coefficient 80 per cent.

June 27, 1899, measured in the same flume as the last measurement. Discharge 0.52 second-foot, width of flume 1.38 feet, depth of water 0.95 foot, surface velocity 0.5 foot per second, coefficient 80 per cent.

August 25, 1899, the discharge at the same place measured 0.4 second-foot, the depth of water was 0.84 foot, surface velocity 0.5 foot per second. Flume in fairly good condition. Coefficient 80 per cent.

March 15, 1900, the discharge measured 0.68 second-foot, same place, same conditions. The depth of water was 0.62 foot, the surface velocity 1 foot per second, coefficient 80 per cent.

June 14, 1900, at 2 p. m., the discharge measured 0.5 second-foot at the same place; the sectional area was 1.14 square feet, the surface velocity 0.59 foot per second, coefficient 75 per cent.

Upper canal of Riverside Water Company.—On June 30, 1898, the discharge over the headworks weir (see Pl. IX) was 59.04 second-feet. There are three weirs, with end contractions, each 9½ feet long. Head equals 0.677 foot, velocity of approach 1.12, 2.18, and 1.94 feet per second, respectively.

February 28, 1899, the discharge was 60.53 second-feet, the head 0.843 foot.

June 26, 1899, the discharge was 53.92 second-feet, the head 0.686 foot.

August 31, 1899, there were 52.04 second-feet of water flowing over the headworks weir, and the head was 0.67 foot.

March 21, 1900, there were 61.94 second-feet flowing. Head 0.755 foot.

June 23, 1900, at 3 p. m., the discharge at the headworks weir measured 52.94 second-feet; the head was 0.68 foot, average velocity of approach 0.77 foot per second, full contractions.

Lower canal of Riverside Water Company.—Meter measurement on June 17, 1898, at 4 p. m., as determined by Mr. F. H. Olmsted, was 9.27 second-feet.

June 18, 1898, at 10 a. m., Mr. Olmsted made a meter measurement and found a discharge of 11.27 second-feet.

June 27, 1898, there were 10.83 second-feet of water flowing in the flume just below the intake at Santa Ana River. The sectional area was 4.18 square feet, the velocity 3.24 feet per second, coefficient 80 per cent.

September 2, 1898, there were 7.7 second-feet of water flowing at the same place. The water area was 3.84 square feet, the velocity 2.5 feet per second, coefficient 80 per cent.

March 10, 1899, there were 16.20 second-feet flowing over the weir at the end of the flume. Length of weir 5 feet, head 1.01 feet, two full end contractions, velocity of approach less than 1 foot per second.

June 28, 1899, the discharge at the same place measured 9.09 second-feet, the water area was 3.63 square feet, the surface velocity 3.12 feet per second, coefficient 80 per cent.

September 1, 1899, the discharge in the flume measured 7.38 second-feet, the water area was 3.33 square feet, the surface velocity 2.77 feet per second, coefficient 80 per cent.

June 23, 1900, at 9.05 a. m., the discharge measured 7.16 second-feet in the flume; sectional area 3.4 square feet, surface velocity 2.63 feet per second, coefficient 80 per cent.

Gage canal.—On June 29, 1898, this canal was measured at its intake from Santa Ana River. The discharge was 1.16 second-feet over a weir 5 feet long, head 0.17 foot, velocity of approach 0.5 foot per second, no end contractions.

March 7, 1899, the discharge measured 0.72 second-foot, length of weir 5 feet, head 0.125 foot, velocity of approach less than 1 foot per second, no end contractions.

June 20, 1899, the discharge over the same weir measured 0.24 second-foot, head 0.06 foot.

August 25, 1899, the discharge over a weir 1 foot in length measured 0.64 second-foot, head 0.35 foot, velocity of approach less than 1 foot per second, two full contractions.

March 1, 1900, the discharge over the same weir measured 0.395 second-foot, head 0.25 foot.

June 7, 1900, the discharge measured 0.29 second-foot over same weir, head 0.2 foot, velocity of approach less than 0.5 foot per second, two full end contractions.

Gage canal at Palm avenue weir.—June 30, 1898, Mr. K. Sanborn and Mr. J. B. Lippincott measured the flow over the weir, and obtained a discharge of 27.42 second-feet. The weir was 13.34 feet in length, with a head of 0.7 foot. There were two contractions. The velocity of approach was 1.4 feet per second. The level of the water below the weir was the same as the elevation of the crest, or knife edge.

September 21, 1898, there were 26.238 second-feet of water flowing over this weir. The head was 0.709 foot, the velocity of approach 1 foot per second, two full contractions.

March 7, 1899, the discharge over the weir measured 27.4 second-feet, head 0.73 foot, velocity of approach less than 1 foot per second.

June 26, 1899, the discharge measured 25.46 second-feet, head 0.69 foot.

August 15, 1899, the discharge measured 24.11 second-feet, head 0.67 foot.

March 21, 1900, the discharge measured 22.36 second-feet, head 0.639 foot.

June 7, 1900, the discharge measured 22.52 second-feet, head 0.64 foot, velocity of approach less than 1 foot per second.

Daley ditch.—Measured at 5.15 p. m. on June 29, 1898, by J. B. Lippincott and K. Sanborn. Discharge in flume across City Creek was 0.63 second-foot, water area 0.4 square foot, surface velocity 1.95 feet per second, coefficient 80 per cent.

September 12, 1898, at 11.30 a. m., the discharge measured 0.67 second-foot; water area 0.42 square foot, surface velocity 2 feet per second, coefficient 80 per cent.

March 1, 1899, the discharge measured 0.71 second-foot, the water area 0.354 square foot, surface velocity 2.5 feet per second, coefficient 80 per cent.

June 27, 1899, the discharge measured 0.51 second-foot, water area 0.32 square foot, surface velocity 2 feet per second, coefficient 80 per cent.

August 28, 1899, the discharge measured the same as on June 27, 1899.

March 15, 1900, the discharge measured 0.72 second-foot, water area 0.45 square foot, surface velocity 2 feet per second, coefficient 80 per cent.

June 23, 1900, at 12 m., the discharge measured 1.12 second-feet, the sectional area 0.28 square foot, the surface velocity 5 feet per second, coefficient 80 per cent.

McIntyre ditch.—June 12, 1898, at 4.25 p. m., the discharge measured 0.37 second-foot in flume near the head; the water area was 1.48 square feet, surface velocity 2.5 feet per second, coefficient 80 per cent.

September 14, 1898, the discharge measured 0.038 second-foot over a weir near the headworks, which was 0.5 foot in length; head 0.083 foot, no velocity of approach, two full end contractions.

March 1, 1899, the discharge measured 0.82 second-foot over a weir 1 foot in length; head 0.45 foot.

June 23, 1899, the discharge over the same weir measured 0.149 second-foot; head 0.13 foot.

August 26, 1899, there was no water flowing.

March 16, 1900, the discharge over the same weir measured 0.143 second-foot; head 0.126 foot.

June 12, 1900, the discharge over the same weir measured 0.01 second-foot; head 0.026 foot, two full contractions, velocity of approach less than 0.5 foot per second.

Whiting ditch.—June 27, 1898, the discharge measured 0.26 second-foot over a weir 1 foot in length near the headworks; head 0.19 foot, velocity of approach less than 0. 5 foot per second, two full end contractions.

September 14, 1898, the discharge measured 0.01 second-foot over a weir 0.5 foot in length; head 0.036 foot, velocity of approach less than 0.05 foot per second, two full end contractions.

March 1, 1899, the discharge measured 0.76 second-foot over a weir 1 foot in length; head 0.395 foot, velocity of approach less than 0.5 foot per second, two full end contractions.

June 27, 1899, the discharge over the same weir measured 0.246 second-foot; head 0.182 foot.

August 26, 1899, the discharge over the same weir measured 0.009 second-foot; head 0.02 foot.

March 1, 1900, the discharge over the same weir measured 1.12 second-feet; head 0.522 foot.

June 12, 1900, the discharge measured 0.13 second-foot over the same weir; head 0.12 foot, velocity of approach less than 0.25 foot per second, two full end contractions.

Swamp ditch.—September 1, 1898, there were 1.02 second-feet flowing in flume to the Riverside Water Company's Rice-Thorne flume; the water area was 0.32 square foot, the surface velocity 3.5 feet per second, coefficient 80 per cent.

February 28, 1899, the discharge measured 0.85 second-foot over a weir at the first distributing box; length of weir 1 foot, head 0.427 foot, velocity of approach less than 0.5 foot per second, two full end contractions.

June 20, 1899, the discharge over the same weir measured 0.77 second-foot; head 0.4 foot.

August 30, 1899, the discharge over the same weir measured 0.69 second-foot; head 0.37 foot.

March 21, 1900, the discharge over the same weir measured 0.7 second-foot; head 0.374 foot.

June 7, 1900, the discharge over the same weir measured 0.89 second-foot; head 0.44 foot, velocity of approach less than 0.5 foot per second, two full end contractions.

Ranchero ditch.—September 22, 1898, at 1 p. m., the discharge measured 1.64 second-feet over a weir in the cement ditch on the Raynor ranch; length of weir 4 feet, head 0.25 foot, velocity of approach less than 0.5 foot per second, two full end contractions.

March 13, 1899, the discharge measured the same over the same weir.

June 23, 1899, at 4.30 p. m., the discharge over the same weir measured 1 second-foot; head 0.18 foot.

August 26, 1899, the discharge over the same weir measured 0.41 second-foot; head 0.1 foot.

March 17, 1900, the discharge over the same weir measured 0.24 second-foot; head 0.07 foot.

June 12, 1900, the discharge measured 0.55 second-foot in the ditch; sectional area 0.74 square foot, surface velocity 1 foot per second, coefficient 75 per cent.

Ward & Warren ditch.—In June, 1898, this ditch was receiving from the Rice-Thorne canal 1.60 second-feet of water and from the river 0.72 second-foot.

March 10, 1899, there were 3.09 second-feet flowing over a weir 3.33 feet in length near the head of the ditch; head 0.434 foot, velocity of approach less than 0.5 foot per second, two full end contractions.

June 20, 1899, the discharge measured 0.615 second-foot over a weir 1 foot in length near the headworks; head 0.34 foot, velocity of approach less than 0.5 foot per second, two full end contractions.

August 30, 1899, the discharge measured 1.56 second-feet over a weir 2 feet in length near the headworks; head 0.38 foot, velocity of approach less than 0.5 foot per second, two full end contractions.

March 19, 1900, the discharge measured 2.55 second-feet over a weir 3 feet in length at the head of the ditch; head 0.41 foot, velocity of approach less than 0.5 foot per second, two full end contractions.

June 23, 1900, the discharge measured 1.7 second-feet in the ditch just below the dam across Santa Ana River; sectional area 1.95 square feet, surface velocity 1.25 feet per second, coefficient 70 per cent.

Mill flume of Riverside Water Company.—June 15, 1898, there were 3.12 second-feet flowing at the end of the flume near the old Colton mill; water area 1.76 square feet, surface velocity 2.22 feet per second, coefficient 80 per cent.

September 12, 1898, at 3.35 p. m., there were 3.36 second-feet at the same place; water area 1.68 square feet, surface velocity 2.5 feet per second.

February 28, 1899, there were 5.3 second-feet at the same place; water area 2.208 square feet, surface velocity 3 feet per second, coefficient 80 per cent.

June 26, 1899, the discharge measured 7.29 second-feet at the same place; water area 3.04 square feet, surface velocity 3 feet per second, coefficient 80 per cent.

August 30, 1899, the discharge measured 2.56 second-feet at the same place; water area 1.6 square feet, surface velocity 2 feet per second, coefficient 80 per cent.

March 9, 1900, the discharge measured 2.67 second-feet; water area 1.52 square feet, surface velocity 2.2 feet per second, coefficient 80 per cent.

June 7, 1900, the discharge measured 2.17 second-feet; sectional area 1.36 square feet, surface velocity 2 feet per second, coefficient 80 per cent.

Colton mill pump of Riverside Water Company.—June 15, 1898, there were 1.94 second-feet flowing over the weir at the old Colton mill; length of weir 4.015 feet, head 0.276 foot, no end contractions, velocity of approach less than 1 foot per second.

September 1, 1898, there were 2.04 second-feet flowing over the same weir; head 0.286 foot.

June 26, 1899, 1.77 second-feet were flowing over the weir; head 0.26 foot.

August 31, 1899, 1.67 second-feet were flowing over the weir; head 0.25 foot.

June 7, 1900, the discharge over the weir measured 1.88 second-feet; head 0.27 foot, velocity of approach less than 1 foot per second, no end contractions.

Camp Carlton ditch.—June 30, 1898, at 4.30 p. m., 0.61 second-foot was flowing over the weir at the Waterman avenue crossing; length of weir 3.33 feet, head 0.146 foot, velocity of approach less than 0.5 foot per second, two full end contractions.

September 12, 1898, at 9.30 a. m., there were 1.2 second-feet flowing over the same weir; head 0.229 foot.

March 7, 1899, there were 2.13 second-feet flowing over the weir; head 0.333 foot.

June 20, 1899, 1.62 second-feet were flowing over the weir; head 0.28 foot.

August 27, 1899, 1.02 second-feet were flowing over the weir; head 0.25 foot.

March 21, 1900, 2.55 second-feet were flowing over the weir; head 0.38 foot.

June 7, 1900, the discharge over the weir measured 2.6 second-feet, head 0.385 foot, velocity of approach less than 1 foot per second, two full end contractions.

East Riverside irrigation district.—It is stated that on June 10, 1898, 4.4 second-feet were being pumped for this district at the head of the Vivienda pipe line.

September 17, 1898, at 4 p. m., measurement showed that 4.43 second-feet were flowing over a weir 3.33 feet in length at the reservoir at the head of the Vivienda pipe line, which runs to East Riverside. Head 0.55 foot, two full end contractions, velocity of approach less than 1 foot per second.

March 13, 1899, 4.25 second-feet were flowing over the same weir; head 0.54 foot.

June 23, 1899, at 4 p. m., there were 2.08 second-feet flowing over the same weir; head 0.33 foot.

March 1, 1900, there were 6.59 second-feet flowing over a weir 4.16 feet long in the tunnel pipe line; head 0.6 foot, no velocity of approach, two full contractions.

June 12, 1900, the discharge over the foregoing weir measured 5.38 second-feet; head 0.542 foot, two full end contractions, velocity of approach less than 1 foot per second.

Colton Terrace Water Company.—June 30, 1898, 1.97 second-feet were flowing over a weir 2 feet in length at Reservoir Hill; head 0.456 foot.

September 22, 1898, 1.61 second-feet were flowing over a weir at the head of the pipe line above First street in San Bernardino; head 0.3 foot, length of weir 3 feet.

March 13, 1899, 1.69 second-feet were flowing over the same weir; head 0.31 foot.

June 26, 1899, 1.3 second-feet were flowing over the same weir; head 0.26 foot.

August 26, 1899, the discharge measured the same as on June 26.

March 17, 1900, the discharge over the same weir measured 1.69 second-feet; head 0.31 foot.

June 12, 1900, the discharge over the same weir measured 1.54 second-feet; head 0.292 foot, velocity of approach less than 1 foot per second, two end contractions.

City of Colton pumping plants.—June 26, 1899, 2.09 second-feet were flowing over a weir 4.17 feet in length at the head of the pipe line of the First street reservoir in San Bernardino; crest of weir 18 inches wide, head 0.29 foot.

August 26, 1899, 1.52 second-feet were flowing over the same weir.

August 26, 1899, the pumping plant west of Mount Vernon avenue was discharging 2.37 second-feet over a weir 2 feet long in the pipe line; head 0.52 foot, two full contractions, velocity of approach less than 0.5 foot per second.

March 17, 1900, the First street pumps were discharging 2.57 second-feet over a weir 4.15 feet long, crest 18 inches wide, head 0.33 foot, two full contractions, velocity of approach less than 0.5 foot per second.

June 12, 1900, the discharge of the two pumping plants measured 3.21 second-feet. The First street pump was discharging 1.23 second-feet over a weir 4.15 feet long at the head of the pipe line; head 0.23 foot, velocity of approach less than 0.5 foot per second, two full contractions. The Mount Vernon avenue pumps were discharging 1.98 second-feet over a weir 2 feet long in the reservoir; head 0.46 foot, two end contractions, velocity of approach less than 0.5 foot per second.

Whitlock ditch.—June 29, 1898, at 5 p. m., the discharge measured 0.34 second-foot in the flume on Styles street across the McKenzie ditch; the water area was 2.65 square feet, surface velocity 1.6 feet per second, coefficient 80 per cent.

October 6, 1898, the discharge in the flume measured 0.38 second-foot, water area 0.338 square foot, velocity of approach 1.42 feet per second, coefficient 80 per cent.

March 1, 1899, the discharge in the flume measured 0.47 second-foot, water area 0.59 square foot, velocity of approach 1 foot per second, coefficient 80 per cent.

June 27, 1899, the discharge in the flume measured 0.277 second-foot, water area 0.6 square foot, velocity of approach 0.66 foot per second, coefficient 80 per cent.

August 28, 1899, the discharge in the flume measured 0.094 second-foot, water area 0.147 square foot, surface velocity 0.8 foot per second.

March 15, 1900, the discharge in the same flume measured 0.232 second-foot, water area 0.145 square foot, surface velocity 1 foot per second.

June 23, 1900, the ditch at this point was dry.

Bloomington flume.—September 17, 1898, at 4.00 p. m., the Bloomington flume was discharging 5.49 second-feet of water over a weir 2 feet in length at the upper end of the flume. That weir was submerged 0.41 foot; the head was 0.96 foot, velocity of approach less than 0.5 foot per second, two end contractions.

June 23, 1899, 5.930 second-feet were flowing over the same weir. The weir was submerged 0.19 foot, the head was 0.95 foot, velocity of approach 2 feet per second, two end contractions.

August 26, 1899, 3.05 second-feet were flowing over the same weir, which was not submerged. The head was 0.62 foot.

March 16, 1900, the weir at the upper end of the flume was found to be destroyed; 3.8 second-feet were measured by floats at the lower end of the flume; the water area was 3.05 square feet, surface velocity 1.66 feet per second, coefficient 80 per cent.

June 12, 1900, the discharge near the end of the flume measured 3.68 second-feet, sectional area 3.93 square feet, surface velocity 1.25 feet per second, coefficient 75 per cent.

Johnson & Hubbard pumping plant.—March 16, 1900, 1.26 second-feet were flowing in the flume at the lower end of the pipe line just east of Colton. The water area was 1.1 square feet, surface velocity 1.43 feet per second, coefficient 80 per cent.

Comparative amounts of water, in second-feet, flowing in canals above Colton.

Name of ditch.	June, 1898.	Sept., 1898.	Mar., 1899.	June, 1899.	Aug., 1899.	Mar., 1900.	June, 1900.	Sept., 1900.
Haws & Talmage	0.84	0.00	0.28	0.00	0.00	0.00	0.00	0.00
Rabel Dam	5.37	3.07	2.36	1.54	.94	.54	.35	.07
Shay or Stout Dam	2.30	2.08	2.23	1.13	.90	.507	.40	.16
McKenzie	2.54	2.08	9.40	3.86	2.00	2.30	1.57	1.69
Meeks & Daley	8.42	[b]17.00	17.00	15.48	10.45	13.94	13.78	14.68
Beam	.67	[b].65	.72	.52	.40	.68	.50	.33
Riverside Water Co., upper canal[a]	59.04	61.34	60.53	53.92	52.04	61.94	52.94	61.02
Timber	.00	.00	.00	.00	.00	.00	.00	.00
Gage canal, Santa Ana River	1.16	1.16	.72	.24	.64	.395	.29	.17
Gage canal, Palm avenue	[c]26.26	[c]25.07	[c]26.68	[c]25.22	[c]23.47	[c]21.96	[c]22.23	[c]27.85
Logsdon & Farrel	.72	.63	1.61	1.15	.54	1.26	.49	.20
Whitlock	.34	.38	.47	.28	.094	.23	.00	.00
Daley	.63	.67	.71	.51	.51	.72	1.12	.54
McIntyre	.37	.038	.82	.15	.00	.14	.01	.00
Whiting	.26	.01	.76	.246	.01	1.12	.13	.00
Swamp	1.00	1.02	.85	.77	.69	.70	.89	.86
Ranchero	[b]1.75	1.64	1.64	1.00	.41	.24	.55	1.33
Ward & Warren	2.32	[b]2.32	3.09	.615	1.56	2.55	1.70	.53
Mill flume, Riverside Water Co.	3.12	3.36	5.30	7.29	2.56	2.67	2.17	.94
Mill pump, Riverside Water Co	1.94	2.04	([d])	1.77	1.67	([d])	1.88	1.52
Camp Carlton	.61	1.20	2.13	1.62	1.02	2.55	2.60	1.67
East Riverside	4.40	4.43	4.25	2.08	2.00	6.59	5.38	3.70
Colton Terrace Water Co	1.97	1.61	1.69	1.30	1.30	1.69	1.54	1.53
City of Colton	6.82	7.40	3.20	5.49	3.89	4.94	3.21	3.54
Bloomington flume	5.26	5.49	([d])	5.93	3.05	3.80	3.68	3.28
Total	138.11	144.69	146.44	132.11	110.14	131.46	117.41	125.61

[a] Above Slover Mountain. [b] Interpolated. [c] River water not included. [d] Pumps not run.

Return water, natural flow in second-feet, compared with developed water in San Bernardino Valley above Colton.

Name of ditch.	June, 1898.		September, 1898.		March, 1899.		June, 1899.	
	Developed.	Natural.	Developed.	Natural.	Developed.	Natural.	Developed.	Natural.
Haws & Talmage		0.84		0.00		0.28		0.00
Rabel Dam		5.37		3.07		2.36		1.54
Shay or Stout Dam		2.30		2.08		2.23		1.13
McKenzie		2.54		2.08		9.40		3.86
Beam		.67		.65		.72		.52
Riverside Water Co., upper canal	18.00	41.04	17.54	43.80	18.04	42.49	17.50	36.42
Gage canal, Santa Ana River		1.16		1.16		.72		.24
Gage canal, Palm avenue weir	26.26		25.07		26.68		25.22	
Logsdon & Farrell		.72		.63		1.61		1.15
Whitlock		.34		.38		.47		.28
Daley		.63		.67		.71		.51
McIntyre		.37		.038		.82		.15
Whiting		.26		.010		.76		.246
Swamp		1.00		1.020		.85		.77
Ranchero		[a]1.75		1.640		1.64		1.00
Ward & Warren	1.60	.72	1.60	.720	1.60	1.49	.615	
Mill flume of Riverside Water Co.		3.12		3.360		5.30		7.29
Mill pump of Riverside Water Co.	1.94		2.04		Not run.		1.77	
Camp Carlton ditch	.61		1.20		2.13		1.62	
East Riverside district, or Riverside Highland Water Co	4.40		4.43		4.25		2.08	
Colton Terrace Water Co.	1.97		1.61		1.69		1.30	
City of Colton pumping plant	6.82		7.40		3.20		5.49	
Bloomington flume	5.26		5.49		.00		5.93	
Meeks & Daley ditch		8.42		[a]17.00		17.00		15.48
Total	66.86	71.25	66.38	78.31	57.59	88.85	61.525	70.59

Name of ditch.	August, 1899.		March, 1900.		June, 1900.		September, 1900.	
	Developed.	Natural.	Developed.	Natural.	Developed.	Natural.	Developed.	Natural.
Haws & Talmage		0.00		0.000	0.00	0.00		0.00
Rabel Dam		.94		.540		.35		.07
Shay or Stout Dam		.90		.507		.40		.16
McKenzie		2.00		2.300		1.57		1.69
Beam		.40		.380		.50		.33
Riverside Water Co., upper canal	27.50	24.54	24.54	37.40	32.36	20.58	27.00	34.02
Gage canal, Santa Ana River		.64		.395		.29		.17
Gage canal, Palm avenue weir	23.47		21.96		22.23		27.85	
Logsdon & Farrell		.54		1.26		.49		.20
Whitlock		.09		.23		.00		.00
Daley		.51		.72		1.12		.54
McIntyre		.00		.14		.01		.00
Whiting		.01		1.12		.13		.00
Swamp		.69		.70		.89		.86
Ranchero		.41		.24		.55	.80	.53
Ward & Warren	1.56		1.60	.95	1.60	.10	.53	
Mill flume of Riverside Water Co		2.56		2.67		2.17		.94
Mill pump of Riverside Water Co.	1.67			Not run.	1.88		1.52	
Camp Carlton ditch	1.02		2.55		2.60		1.67	
East Riverside district, or Riverside Highland Water Co.	2.00		6.59		5.38		3.70	
Colton Terrace Water Co.	1.30		1.69		1.54		1.53	
City of Colton pumping plant	3.89		4.94		3.21		3.54	
Bloomington flume	3.05		3.80		3.68		3.28	
Meeks & Daley ditch		10.45		13.94		13.78		14.68
Total	65.46	44.68	67.67	63.79	74.48	42.93	71.42	54.18

[a] Interpolated.

From the two preceding tables it will be noted that despite severe droughts which existed from 1898 to 1900, inclusive, the output of water from the gravel beds above Colton has but slightly diminished, the total being 144.69 second-feet in September, 1898, as compared with 125.61 second-feet in September, 1900. The amount of developed water in September, 1898, was 66.38 second-feet and in September, 1900, 71.42 second-feet, while the natural return water between the same dates decreased from 78.31 second-feet to 54.18 second-feet. During this period much development work was done, and while these new supplies do not mean an absolute addition to the output from the district, the fact that the total supply was maintained notwithstanding the drought is a decided achievement.

The most important question in considering this underground water supply is the rate at which the gravel beds will be recharged during wet years. This underground reservoir is of such magnitude, however, that it will require a term of years to demonstrate what these conditions are. Certainly more water can not be permanently pumped from a reservoir than its mean inflow. During this investigation an effort has been made to determine the elevation of the water plane throughout the valley above Colton, as shown on Pl. I. During the last four years the plane of saturation has been lowered. After a cycle of rainy years observations of these same wells should be taken to determine what the rise, if any, in the water plane has been. Not until this has been done will it be possible to state whether the supply is of a permanent nature. The data now at hand, though meager, indicate that 140 second-feet can with safety be continuously withdrawn, but this amount should not be greatly increased.

WELLS.

There are a large number of artesian wells near San Bernardino and Colton, in the basins of Santa Ana River, Lytle Creek, and Warm Creek. On page 530 of Physical Data and Statistics of California, published by the State engineering department in 1886, is given a list of 408 artesian wells above Colton, 208 of which were measured and found to be discharging 20.11 second-feet. Nearly all of these wells must have been near San Bernardino and Colton, and all of them must have been in San Bernardino Valley. In 1898 the wells in Santa Ana River Basin proper that supply irrigation water were all flowing wells. In the basin of Lytle Creek the wells are more numerous, and are owned either by individuals or by small corporations. In the town of San Bernardino many artesian wells have been bored for domestic purposes during the last twenty years, which when properly capped furnished water under pressure to many houses. These wells are from 200 to 400 feet deep, and all are driven through layers

of clay and gravel. They cost (in 1898), cased, from $1 per lineal foot for 4-inch wells to $2 per lineal foot for 10-inch wells. Some of them furnished as much as 50 miners' inches of water; many of the smaller wells flowed only 3 to 5 miners' inches. During the last four years many of these wells in the city of San Bernardino have ceased to flow, and the discharge of all of them has greatly decreased. These wells afford a very cheap water supply in a locality where the large irrigation companies charge from 5 to 20 cents for a run of 1 miners' inch for twenty-four hours. The area of artesian lands in this basin was 32 square miles in 1897 and 15 square miles in 1900. The irrigation companies have purchased these water-bearing lands. About fifty wells have been sunk in the Lytle Creek Basin. The prices at which the lands are sold vary widely. In August, 1888, the Riverside Water Company paid $25,000 for 40 acres of artesian land in the Warm Creek bottoms. In 1898 the same company bought the water right to 72 acres of excellent artesian lands in the Warm Creek Basin for $50 an acre. The latter price has also been paid in several localities northwest of San Bernardino, between the Lytle Creek Wash and the mesa to the west, which seems to be an extension of the Bunker Hill dike. Pumping plants have been placed in many of the wells, and the supply has thus been increased. The result has been to very largely exhaust the small domestic wells in the city of San Bernardino, and it would now appear that it has become a contest between the owners of the pumping plants as to which shall control the water. It probably is largely a question of pumping out an underground reservoir, and the man who taps it lowest down and has the strongest pump will get the most water. The results of a series of interesting experiments made by Prof. E. W. Hilgard on the wells at the head of the Gage system are given under the description of the water supply of that system. These experiments show that in April, 1889, capping and uncapping 27 adjoining flowing wells did not produce an immediate effect upon the surrounding wells.

The table on pages 84 and 85, showing the effect of opening and closing neighboring artesian wells of the Gage canal system, is also of interest in considering this matter. Observations of 55 wells were made in October, 1892, and while the volume of water increased as more wells were sunk, the aggregate flow is not so great, by 52 per cent, as the sum of the flow of the individual wells when all of the wells except one were closed.

The question whether the water supply in the aggregate can permanently be increased by digging larger wells and pumping is of course a vital one in this connection. An artesian basin is practically an underground reservoir. In this case it is probably refilled during wet years, principally by the winter floods from the surrounding mountain drainage basins and from the return water from irrigation. When the reservoir is filled the basin runs over at its rim and permits

larger surface flow. The wells tapping this basin at its lowest depression probably occupy the most favored positions, and those at the upper rim the poorest positions. All draw from the same source, and it is exceedingly difficult to tell which wells are responsible for the draining of those that have failed. It is claimed by the owners of the newer pumping plants that the failure of the wells that ceased to flow in 1898 is due to the series of dry years that preceded.

During the winter of 1897–98 there were very few floods, and even the normal winter flow of the streams was diverted for irrigation purposes. The same condition prevailed in the winters of 1898–99 and 1899–1900. The points of diversion on some of the surrounding streams have been moved higher up into the canyons and tunnels run under the stream beds to bed rock, which tends to decrease the supply of artesian water. While the wells near San Bernardino have failed and the wells in the Lytle Creek Basin have fallen from 19.12 second-feet in June to 13.94 second-feet in September, those in the lower central portion of the main valley have held their own. There is apparently no redress at law for those whose wells have failed, because it is difficult to show any direct stream relation between given groups, and at present the law does not take cognizance of so complex conditions.

The more an artesian basin is drawn upon the greater will be its storage capacity in unfilled voids during the following season; consequently it is possible that the total output from this basin may be permanently increased by tapping it more extensively in the lower levels. As a water supply is controlled absolutely by its minimum production, and as many of the artesian wells about San Bernardino failed during the summer of 1898, it is clear that the limit of artesian supply near the 1,100-foot contour has been reached. The limit of maximum available supply entering the artesian reservoir is governed by the area of the intake, the velocity of the entering water through the intake, and the length of time during which the entering water is available. These conditions are manifestly difficult of determination.

The large number and the great capacity of wells that have been bored in the lower regions of the artesian belt have so nearly approached the carrying capacity of the gravel and have so diminished the pressure at the lower wells that it is difficult to obtain a definite idea of the elevation at which water may be found in the upper regions of the artesian belt. A distinct grade is very noticeable in the crest of all wells when their pressure is considered. The flowing of water from these wells is changed from a condition of hydrostatics to one of hydraulics. It is of interest to note that when a well has an even flow over its casing, so that the height of rising water in the center of the well above the casing can be accurately measured, this height may be considered as the head on a weir, the length being

the circumference of the pipe, end contractions being eliminated. The probable error in this computation ordinarily will not exceed 4 per cent.

All of the wells in San Bernardino Valley in the Redlands and San Bernardino quadrangles, irrespective of their size or producing capacities, were visited by the representatives of the Geological Survey during the summer of 1900. The 412 wells in the Redlands quadrangle were inspected by Mr. Louis Mesmer, of Los Angeles, Cal., and the 478 wells in the San Bernardino quadrangle were inspected by Mr. C. J. Roney, observer. The results of their observations are contained in Part II of this report—Water-Supply and Irrigation Paper No. 60.

Artesian wells of the Riverside Water Company.—During the last thirteen years the Riverside Water Company has sunk 70 artesian wells in the Warm Creek Basin east of Colton and San Bernardino, varying in depth from 60 feet to 590 feet and in diameter from 6 inches to 10 inches. The largest well developed by the company previous to 1898 was in the bottom land of Santa Ana River, in lot 2, block 54, San Bernardino Rancho, about 2 miles east of the town of Colton. In the spring of 1898 the managers of the Riverside Water Company decided to increase this development by sinking numerous shallow wells 8 or 9 inches in diameter about 300 feet apart, and close enough to discharge their waters directly into the company's main conduit leading to Warm Creek. For this purpose two hand rigs were procured and 13 wells were sunk, at an average cost of $1.75 per foot, the result being an increase of 282 miners' inches (5.64 second-feet). These wells were bored through alternate layers of sand and clay to water-bearing gravel and bowlders by means of derricks and sand pumps.

The total output of this tract, as measured June 30, 1898, was 554 miners' inches (11.09 second-feet), 79 miners' inches (1.58 second-feet) of which goes to the Ward & Warren ditch, the remaining 445 miners' inches (9.51 second-feet) being delivered into Warm Creek just above the Riverside Water Company's upper canal diversion.

One of the largest wells was sunk on the south side of Warm Creek in lot 11, block 51, San Bernardino Rancho. It was commenced in January, 1898, and was completed in February, 1898, the total cost being $1,100. It is 590 feet deep, has a 10-inch casing of No. 10 iron, B. W. G. The water all comes from the bottom, and when completed the well flowed 120 miners' inches (2.4 second-feet). During the summer of 1898 a basin was placed around this well and connected by a pipe to the main channel of Warm Creek. Twelve feet of pipe was cut off from the top of the well to make it correspond with the bed of Warm Creek. This increased the flow to 150 miners' inches (3.0 second-feet). The cost of water from this well was $7.33 per miners' inch. There are seven wells on this tract, the aggregate flow

of which in August, 1898, was 340 miners' inches (6.8 second-feet). This water is carried in a vitrified clay pipe direct to the natural channel of Warm Creek, with whose waters it mingles, and on its course toward Riverside is allowed to pass through the various head gates of the irrigating ditches and is not deducted from the other stream measured at the Riverside Water Company's upper canal.

During the months of March and April, 1900, the Riverside Water Company sunk three wells, to an average depth of 552 feet, in block 44 of the San Bernardino Rancho. The water all comes from the extreme bottom of these wells. The pipes are 10 inches in diameter, of No. 12 iron, B.W.G. On May 19, 1900, the total flow of these three wells was 420 miners' inches (8.40 second-feet).

Martius well.—The Martius well, at Tippecanoe station, on the Riverside Motor Railroad, may be taken as a type of numerous pumped dug wells. It was excavated in 1893, is 20 feet deep and 12 feet in diameter. The wall is of dried brick laid on a wooden toe of crib work. Mr. Martius says that at first he used a steam engine to run the pump, but the cost was $3 for a day of ten hours. He now (1900) uses a 9-horsepower Webber gasoline engine, and the cost of pumping is $1.30 a day, or at the rate of 1.44 cents per horsepower per hour. A centrifugal pump is used, and 15 miners' inches (0.30 second-foot) of water are raised. This water is used for irrigation and street sprinkling. Ordinarily the cost of gasoline for power is about 33 per cent less than this amount.

PUMPING PLANTS.

One feature of special interest in the pumping plants in this valley is the use of electric motors for developing power. The mountain streams enter the valley on very heavy grades, and when diverted from their canyons into canals they obtain as much as 400 or 500 feet head in 4 or 5 miles length of conduit. The water is then dropped through large steel pressure pipes to nozzles which play on impulse water wheels of the Pelton, Knight, or Tuthill make.[a] These wheels have velocities so high that they can be coupled on the same shaft with the dynamos, thus eliminating loss by gearing. By means of transformers the voltage of the current to be transmitted is "stepped up" to from 20,000 to 40,000 volts, i. e., it is driven over the transmission line under very heavy pressure to the point where it is intended to be used. It is then "stepped down" to a low voltage for the motor which drives the pump. The 3-phase motor is the machine usually employed for this work. Numerous plants of this class have been in service in this locality for the last two years. They give little or no trouble, and are easily started under a load. One attendant can watch three or four of these plants when they are situated within distances of

[a] For description of some of these power plants, see Nineteenth Ann. Rept. U. S. Geol. Survey, Pt. IV.

from a half to a fourth of a mile of one another. The 20-horsepower motor and the centrifugal pump is the most popular plant. The motor is spherical in shape and only 4 feet in diameter. The amount of current used for power is metered and paid for at meter rates. Single or 2-phase motors have been tried for this work, but difficulty is found in starting them under a load. A secondary small machine called an "exciter" has been used in starting them, but even then trouble is experienced. The method of obtaining power by the simple turning of a switch, without the usual accompaniments of dirt and heat and with the little attendance that is required by a plant of this character, is ideal. It is a great improvement over the gas engine. Motors running horizontally, attached to the vertical shaft of the centrifugal pump, are now (1900) made, and give increased efficiency.

Descriptions of the pumping plants located east of Mount Vernon avenue, San Bernardino, in the Lytle Creek bottom, are given below. It is difficult to determine the volume of water pumped, as the pumps do not run with uniform speed and usually discharge into pipe lines. The statements of owners as to volumes discharged have usually been accepted, and while the amounts they give are probably somewhat in excess of the average flow, this will tend to compensate for a number of minor flowing wells or windmill plants not visited or considered in this connection.

East Riverside Pumping Company, Raynor ranch.—In June, 1898, the East Riverside Pumping Company was using at one of its wells a General Electric 20-horsepower 3-phase motor under 550 volts pressure. The power is measured by meter and costs (1898) 1 cent per hour per horsepower for 20-hour days, or $6 a month. The power is furnished by the Redlands Electric Light and Power Company and is developed at the drop in the Mill Creek Canyon. In 1898 the electric motor was consuming 16 horsepower and was lifting 85 miners' inches of water (1.7 second-feet) 28 feet high with a Byron-Jackson No. 6 centrifugal pump discharging through a 6-inch pipe. The total output from the plant of this company is 221 miners' inches (4.43 second-feet), as determined by weir measurement in September, 1898. The water is carried through the Vivienda pipe line to the East Riverside irrigation district.

City of Colton pumping plant.—The pumping plant of the city of Colton furnishes water for irrigation and domestic use at and near that city. Two of the wells (Nos. 2 and 3) are located on what is known as the Barnhill and Lamb tract, block 25, San Bernardino Rancho. The third well is on the south line of First street. All are in the Lytle Creek Basin. These wells are locally known by numbers.

Well No. 1 has a General Electric 20-horsepower 3-phase motor applying 14 horsepower in running a No. 6 Byron-Jackson vertical centrifugal pump, and on June 27, 1898, it was lifting 121 miners' inches (2.42 second-feet) 35 feet high per day of 20 hours, which is

equivalent to 101 miners' inches (2.02 second-feet) for a 24-hour day. This is a cased well.

Well No. 2 is a 10-inch cased well. A General Electric 20-horsepower 3-phase motor of 550 volts capacity is running a No. 10 Byron-Jackson horizontal centrifugal pump, and in June, 1898, was said to be lifting 60 miners' inches (1.2 second-feet) of water 34 feet high per day of 20 hours, equivalent to 50 miners' inches (1 second-foot) for a 24-hour day. On September 22, 1898, this plant was furnishing 31 miners' inches (0.62 second-foot), weir measurement.

Well No. 3 is a 10-inch cased well on the Lamb tract. A 10-horsepower 3-phase electric motor with a capacity of 550 volts is running a Byron-Jackson horizontal centrifugal pump which on June 27, 1898, was raising 50 miners' inches (1 second-foot) of water 35 feet high per day of 20 hours, equivalent to 42 miners' inches (0.83 second-foot) for a 24-hour day. This plant is running with remarkable smoothness, there being no jar and scarcely any appreciable sound from either pump or motor.

Well No. 4 supplies the domestic service of Colton. It is of special interest owing to the grouping of the wells that are operated from one centrifugal pump. The pump is 16 feet below the surface of the ground, in a pit. The suction pipe from the pump is

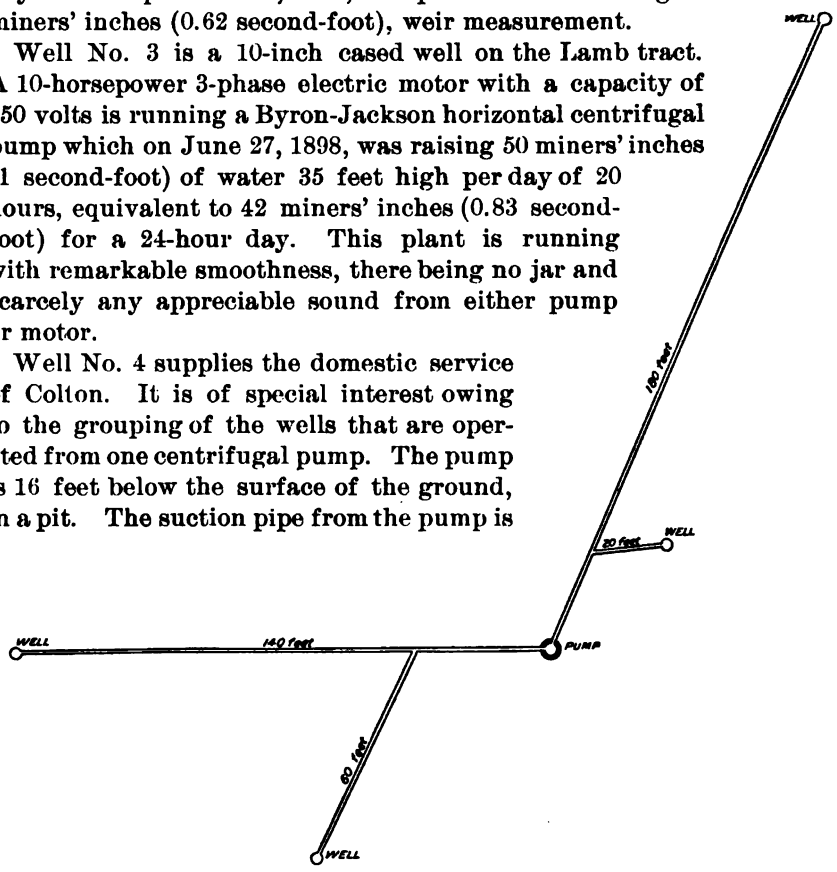


FIG. 1.—Plan of city of Colton pumping plant, showing group of wells operated by one centrifugal pump.

led to four cased wells. A deep trench was dug for these pipes. Fig. 1 shows the location of the wells and pump. This plant is located northwest of the Santa Fe Railroad, at the crossing of Lytle Creek. The pump was originally situated on the surface of the ground, but during the summer of 1898 it was lowered 16 feet, all of the connections of the wells being lowered also. The pump is a No. 8 Byron-Jackson vertical centrifugal, and is operated by a General Electric 20-horsepower 3-phase motor, which is developing 24 horsepower. On June 27, 1898,

A. PUMPING PLANT NEAR EL MONTE.

B. AIR-PUMPING PLANT NEAR COLTON.

110 miners' inches (2.2 second-feet) of water were being pumped, and on September 22, 1898, 150 miners' inches (3 second-feet), per day of 20 hours. The wells are all 10-inch cased wells. The pumps were lowered because of the falling of the water plane. The plant is entirely successful. A plant of similar design is located near Exeter, Cal., in the bottoms of Kaweah River.

Pomeroy & Marble wells.—The pumping plant of the Colton Terrace Citrus Land Company is at the corner of Mount Vernon avenue and Mill street, San Bernardino. A No. 4 Byron-Jackson horizontal centrifugal pump is run by an 8-horsepower gasoline engine. There is one well (cased) 100 feet deep, from which on June 18, 1898, 40 miners' inches (0.80 second-foot) were being lifted 32 feet. On that date there was also an artesian well furnishing water to this system from this locality. The latter well was flowing 40 miners' inches (0.8 second-foot).

Colton Terrace Orange Land and Water Company.—The wells of this company are four in number and are from 200 to 300 feet deep. They are 7-inch cased wells and are about 150 feet apart. This plant is of special interest, as the water is lifted by an air system. A 20-horsepower single-phase electric motor costing $700 was originally used to operate a Stillwell-Bierce air compressor. The electric motor was a failure and it was replaced by steam. From the air compressor the air is conveyed through a reservoir to a distributing pipe system. Thirteen horsepower is now being expended; but it is proposed to increase the number of wells, when more power will be required. The wells are bored and cased and a ¾-inch air pipe is run down to almost the bottom of each well. A stopcock is placed near each well to regulate the volume of air entering it. (See Pl. VIII, *B*.) The water is raised by the expansion of the air in the lower portion of the well pipe. The feature of special value in the system is that the lifting force can be indefinitely distributed to the numerous wells in the various localities. The illustration (Pl. VIII, *B*) shows a well into which an excessive amount of air has been admitted. Ordinarily just enough air is passed to produce a flow about 2 or 3 inches above the top of the well. The water stands naturally at a level of 20 feet below the surface. On June 30, 1898, the wells were producing 98.5 miners' inches (1.97 second-feet). This system of pumping does not as a rule give a working efficiency of more than 35 per cent and is proving a disappointment in several localities. In 1900 this method of pumping had been discontinued at this plant.

In Pl. VIII, *A*, is shown a pumping plant near El Monte. The water supply is from five cased wells in the gravel beds below the mouth of San Gabriel Canyon. The output is approximately 500 miners' inches.

Bloomington pumping plants.—The water flowing in the Bloomington flume is a combination of 100 miners' inches (2 second-feet) of

Estimated monthly discharge of Santa Ana River and Santa Ana canal 2 miles above mouth of its canyon above Redlands, near Warmsprings.

[Drainage area, 188 square miles.]

Month.		Discharge in second-feet.			Total in acre-feet.	Run-off.	
		Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1896.							
September		91	41	69	4,124	0.41	0.37
October		186	54	71	4,372	.44	.38
November		56	34	37	2,148	.21	.19
December		48	37	39	2,435	.24	.21
1897.							
January		104	35	68	4,179	.41	.36
February		585	77	185	10,282	1.02	.98
March		465	70	124	7,014	.75	.66
April		190	113	150	8,890	.88	.79
May		113	48	76	4,690	.46	.40
June		86	60	79	4,723	.47	.42
July		102	70	83	5,077	.50	.44
August		100	54	75	4,628	.46	.40
The year		585	35	88	62,571	6.25	.47
1897.							
September		81	58	67	3,968	.39	.35
October		270	45	54	3,347	.33	.29
November		59	40	45	2,678	.27	.24
December		38	29	33	2,040	.21	.18
1898.							
January		67	42	49	2,987	.30	.26
February		86	43	48	2,688	.27	.26
March		51	36	40	2,448	.24	.21
April		43	37	39	2,333	23	.21
May		157	34	61	3,727	.37	.32
June		62	40	48	2,840	.28	.25
July		58	38	43	2,625	.26	.23
August		61	36	43	2,653	.26	.23
The year		270	29	48	34,334	3.41	.25
1898.							
September	River	45.0	28.0	38.0	2,223	0.22	0.20
	Canal			2.0			
October	River	36.0	19.0	26.0	1,581	.16	.14
November	do	34.0	18.0	22.0	1,285	.13	.12
December	do	28.0	22.0	22.0	1,364	.14	.12
1899.							
January	River	34.0	21.5	25.9	1,593	.16	.14
	Canal			2.0			
February	River	34.0	26.5	27.3	1,516	.15	.15
	Canal			4.0			
March	River	48.0	24.0	31.6	1,943	.19	.17
	Canal			7.0			
April	River	34.0	21.5	24.5	1,458	.14	.13
	Canal			5.0			
May	River	26.8	19.0	22.2	1,365	.14	.12
	Canal			2.0			
June	River	34.0	19.0	22.1	1,315	.13	.12
	Canal			0.0			
July	River	28.5	19.0	22.3	1,371	.14	.12
	Canal			0.0			
August	River	19.0	11.0	12.7	781	.08	.07
	Canal			0.0			
The year		48.0	11.0	24.7	17,795	1.78	.17
1899.							
September		12	10	12	690	0.07	0.06
October		19	12	17	1,015	.10	.09
November		49	17	21	1,268	.13	.11
December		36	18	23	1,427	.14	.12
1900.							
January		36	19	23	1,414	.14	.12
February		23	20	22	1,222	.12	.12
March		28	20	23	1,414	.14	.12
April		43	19	25	1,488	.14	.13
May		250	20	57	3,505	.35	.30
June		25	19	22	1,309	.13	.12
July		25	11	19	1,168	.12	.10
August		12	9	11	676	.07	.06
The year		250	9	23	16,596	1.65	.12

Estimated monthly discharge of Santa Ana River and Santa Ana canal 2 miles above mouth of its canyon above Redlands, near Warmsprings—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1900.						
September	16	11	12	714	.07	.06
October	16	12	14	861	.08	.07
November	1,564	14	107	6,367	.63	.57
December	31	25	28	1,722	.17	.15
1901.						
January	600	31	78	4,796	.47	.41
February	540	48	194	10,774	1.07	1.03
March	114	45	68	4,181	.41	.36
April	107	39	43	2,559	.26	.23
May	68	35	42	2,582	.25	.22
June	44	30	37	2,202	.22	.20
July	42	34	38	2,337	.23	.20
August	200	31	50	3,074	.31	.27
The year	1,564	11	59	42,169	4.17	.31

Drainage areas of Santa Ana River above Rincon.

	Square miles.
South of Mill Creek	10.0
Mill Creek	46.2
Santa Ana River	208.2
Plunge Creek	17.1
Reservoir between Plunge and City creeks	2.7
City Creek	21.6
Drainage between City and Sand creeks	1.9
Sand Creek	3.2
Little Sand Creek	1.6
Drainage between Little Sand Creek and East Twin Creek	2.5
East Twin Creek	9.2
West Twin Creek	5.3
Drainage between West Twin Creek and Devils Canyon	4.0
Devils Canyon	7.1
Cajon Pass Basin	88.0
Sycamore Flat	2.8
Lytle Creek	51.9
Total mountain drainage above Colton	483.3
Crafton Hills and San Timoteo Basin	135.0
San Bernardino valley lands above Colton	132.0
Total drainage area above Colton	750.3

Mountain drainage above Rincon and below Colton.

	Square miles.
Drainage north of Grapeland	2.7
San Savain Canyon	2.4
Morse Canyon	1.9
East Etiwanda Canyon	3.2
Day Canyon	6.9
Deer Canyon	4.2
Drainage between Deer Canyon and Cucamonga Canyon	3.7
Cucamonga Canyon	11.0

	Square miles.
Drainage between Cucamonga Canyon and San Antonio Canyon	1.2
San Antonio Canyon	26.7
Thompson Creek	5.5
Liveoak Creek	2.7
Total in mountains	72.1
Foothills around Riverside	62.0
Flat valley land between Rincon and Colton	393.0
Temescal Creek hills below Elsinore Lake	163.1
Chino Creek foothills	22.5

Summary of drainage areas.

	Square miles.	
Mountains above Colton	483.3	
Mountains above Rincon and below Colton	72.1	
Total in mountains above Rincon		555.4
Hills above Colton	135.0	
Hills around Riverside	62.0	
Hills of Temescal Creek below Lake Elsinore	163.1	
Hills of Chino Creek	22.5	
Total in hills above Rincon		382.6
Valley above Colton	132.0	
Valley below Colton and above Rincon	393.0	
Total in valley above Rincon		525.0
Total drainage area above Rincon		1,463.0

The precipitation for the seasons 1896–97 and 1900–1901 was about normal. Each year, however, was preceded by droughts. The discharge in second-feet per square mile of drainage basin of Santa Ana River proper, as given in preceding tables, was 0.45 second-foot per square mile in 1896–97, and 0.31 second-foot in 1900–1901. An estimated discharge for normal years of 0.40 second-foot per square mile from the mountainous portion of the basin above Colton is believed to be conservative. As the percentage of run-off increases with the depth of rainfall, the average annual discharge is greater than the run-off in years of average rainfall. The Bear Valley reservoir, which regulates the discharge from a portion of the basin of Santa Ana River, was completely emptied during both of the years mentioned, and consequently does not affect the totals. A portion of the larger floods are known to pass Colton, and are permanently lost so far as the gravel beds above Colton are concerned. Little surface run-off would occur from the flat and sandy valley lands and hills, but certainly an appreciable amount of the rainfall would sink into the ground and increase the underground supply. The latter supply is believed to be sufficient to offset the loss due to a portion of the larger floods passing the Colton dike unabsorbed. It is not claimed that these quantities are capable of exact determination. Many and expensive observations would be necessary to ascertain this, but it is thought that an estimate based upon existing data and experiences

gained elsewhere will be of interest on this important subject. While the run-off per square mile of the Cajon Pass Basin is known to be less than that of the Santa Ana proper, that of Mill Creek and Lytle Creek is greater, and the Santa Ana Basin is probably typical of the average. The estimated annual run-off, in second-feet per square mile, from the 483 square miles of mountain drainage basins tributary to San Bernardino Valley above Colton, assuming the run-off to be 0.40 second-foot per square mile, is 193.3 second-feet. During average years probably 50 per cent of this is diverted for irrigation at the mouths of the mountain canyons, and half of the water applied for irrigation may be assumed to be lost by evaporation, the remainder sinking into the ground. Thus one-fourth of the discharge from the mountains may be considered as permanently lost during average years, leaving a net remainder of 75 per cent, or 145 second-feet, as a reasonable estimated annual recharge of these gravels.

In June, 1898, the total seepage and return water entering San Bernardino Valley above Rincon was 274.25 second-feet, as shown in the foregoing tables, and at the same time the aggregate flow from the surrounding mountain drainage basins was 101 second-feet, making a total of 375.25 second-feet. The developed water around Pomona (amount not known), however, is not included, and portions of the return water obtained near Colton and used around Riverside doubtless return to the river above Rincon. It is difficult, however, to analyze the situation further than has been done. Despite the recent dry years the increased flow of the river at Auburndale bridge is in all probability due to increased irrigation in the valley, particularly near Riverside, and is especially significant.

The Cucamonga Water Company derives its water from the Red Hills. The company supplies Cucamonga proper, also North Ontario, and irrigates about 5,000 acres of citrus fruits. In August, 1898, there were in addition 52 miners' inches (1.04 second-feet) of water developed at the mouth of Cucamonga Canyon. The Red Hills are so named from the red clay occurring there, which forms a dike across the sand and gravel drainage lines of Cucamonga Creek. This forces the underground water to the surface, where it appears in springs and cienagas. There is an aggregate length ot 8,000 feet of tunnels in this water-bearing land. There are 36 miles of 6-inch drain tiles in the distribution system.

The following is a compilation of all available measurements:

Discharge measurements, in miners' inches, of cienagas and water developments at Red Hills, near Cucamonga.

EAST SIDE.

Date.	Observer.	Creek div. box, 30-inch line.	Div. box No. 1, 16-inch line and Y tunnel (built 1886-87).	China cienaga.	Lone Star spring or tunnel.	Y tunnel (built prior to 1886).	Cienaga below tunnel No. 1.	Total without Lone Star.	Total.
Sept. 26, 1885	Wm. M. Fitzhugh	225.36	.....	51.73	[a] 2.02	9.61 6.61 16.22	.....	293.31	295.33
Nov. 30, 1886	J. P. Culver	261.43	64.67	11.46	2.02	.....	.....	337.56	339.57
July 24, 1887	F. Eaton	147.50	169.50	[a] 10.00	[a] 2.00	163.00	.....	327.00	329.00
July 13, 1888	J. P. Culver	155.78	183.61	18.10	[b] 13.59	138.62	46.43	357.49	371.08
July 13, 1889	E. T. Wright	184.58	163.57	13.27	9.78	136.23	48.35	361.42	371.20
July 14, 1890	do	260.03	228.53	17.32	10.85	156.01	72.52	505.88	516.73
Do	J. P. Culver	266.82	238.04	18.50	11.25	165.55	72.49	523.36	534.61
July 14, 1893	E. T. Wright	.....	.....	.....	.....	152.42	.....	.....	.....
Sept. 15, 1894	do	160.31	182.84	13.14	[a] 8.00	141.10	41.74	356.29	364.29
June 12, 1895	do	198.53	154.87	21.00	[a] 7.00	[a] 110.60	[a] 44.27	374.40	381.40
Aug. 20, 1896	F. E. Trask	132.40	137.90	11.25	[a] 7.00	.....	.....	281.55	288.55
Aug. 10, 1897	do	104.90	120.10	10.50	[a] 9.42	.....	.....	235.50	244.92
Aug. 5, 1897	N. W. Stowell	.....	.....	.....	9.42	.....	.....	.....	.....
Aug. 13, 1898	F. E. Trask	76.68	95.91	7.84	[d] 47.00	.....	.....	180.43	227.43
Apr. 1, 1899	N. W. Stowell	107.25	98.20	.....	.....	.....	.....	205.45	.....
Do	Newman and Finkle	107.25	98.20	[a] 5.00	[c] 35.60	72.60	.....	210.45	246.05
Aug. 21, 1899	E. T. Wright	[f] 91.58	80.95	.....	([g])	56.17	24.78	172.53	[h] 199.53 247.53
Feb. 3 and 5, 1900.	Newman, Trask, and Finkle.	[f] 97.06	77.22	.....	17.06	54.88	.....	174.28	191.34

[a] Estimated.
[b] Tunnel.
[c] Extent of tunnel begun August 11.
[d] Measurement by N. W. Stowell.
[e] March 15.
[f] Including China cienaga.
[g] Flow, 27.00; pumped, 75.00.
[h] Flow.

Discharge measurements, in miners' inches, of cienagas and water developments at Red Hills—Continued.

WEST SIDE.

Date.	Observer.	Spring northwest of tunnel No. 2, portal.	West of cienaga D.	Picnic spring, cienaga C.	Artesian wells Nos. 1 and 2.	Tiburcio spring.	Tunnel No. 2, on 90-acre tract.	China garden.	Stowell wells and tunnel above 90-acre tract.	Rain previous season.	Total on 90-acre tract.	Grand total for Red Hills.
Sept. 26, 1885	Wm. M. Fitzhugh.	56.47	45.27	[a]9.00	.....	[a]1.00	.....	.....	.....	10.81	111.74	406.07
Nov. 30, 1886	J. P. Culver	9.50	5.70 97.80 .90 104.40	18.40	.....	2.16	.....	([b])	.....	21.83	134.46	474.03
July 24, 1887	F. Eaton	13.67	31.90	10.00	Fall' 97	[a]1.00	.....	[a]16.76	.....	14.50	73.33	402.33
July 13, 1888	J. P. Culver	3.14	38.89	5.38	15.14	1.59	[c]17.70	16.76	.....	17.76	98.60	469.68
July 13, 1889	E. T. Wright	3.94	40.53	17.33	15.14	1.81	54.02	[a]16.76	.....	20.97	149.53	520.73
July 14, 1890	.....do	3.08	71.98	30.53	13.98	.92	[d]73.82	[a]16.76	.....	25.45	211.07	727.80
Do	J. P. Culver	3.14	81.78	31.47	14.29	2.38	75.42	[a]16.76	.....	.....	225.24	759.85
June 29, 1893	E. T. Wright	.....	.....	13.29	.....	.....	.....	.....	.....	19.82	.....	.....
July 14, 1893	.....do	.....	.....	.....	.....	.....	36.45	.....	.....	.....	.....	.....
Sept. 15, 1894	.....do	.....	.....	.....	.....	.....	.....	.....	.....	8.13	.....	.....
June 12, 1895	.....do	.....	.....	.....	.....	.....	.....	.....	.....	20.98	.....	.....
June 14, 1896	N. W. Stowell	.00	22.00	1.00	23.00	.....	[a]18.00	.....	.00	.....	64.00	352.55
Aug. 20, 1896	F. E. Trask	.....	.....	.....	.....	.....	.....	.....	.....	8.11	.....	
Mar. 2, 1897	N. W. Stowell	.....	.....	.....	.....	.....	.....	.....	46.00	.....	.....	.....
Aug. 10, 1897	F. E. Trask	.00	.....	.....	.....	.....	.....	.....	.....	16.74	.....	334.07
Aug. 5, 1897	N. W. Stowell	.00	20.00 7.00 27.00	[a].50	[f]20.25	.00	41.40	.00	.....	.....	89.15	
Aug. 13, 1898	F. E. Trask	.00	.....	.....	.....	.....	.....	.....	.....	8.24	.....	290.93
Aug. 14, 1898	N. W. Stowell	.00	[g]24.00	[a].50	[h]13.00	.00	22.00	.00	.....	.....	63.50	
Apr. 1, 1899	.....do	.....	.....	.....	.....	.....	.....	.....	.....	7.49	.....	.....
Do	Newman and Finkle.	.00	[i]15.49	.....	7.90	.....	.....	.....	.....	.....	.....	.....
Aug. 21, 1899	E. T. Wright	.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	267.14
Aug. 25, 1899	E. T. Wright and F. C. Finkle.	.....	3.13	.....	2.68	.....	61.80	.....	92.40	.....	67.61	
Feb. 3 and 5, 1900.	Newman, Trask and Finkle.	.00	3.91	.....	1.45	.....	.....	.....	.....	.....	.....	252.81
Feb. 11, 1900	Trask and Finkle.	.....	3.81	.56	1.20	.....	55.90	.....	76.25	.....	61.47	

[a] Estimated.
[b] China garden included in cienaga D.
[c] Construction begun in January, 1888.
[d] Length, 2,600 feet.
[e] Caved in.
[f] August 4, well No. 2 cut.
[g] June 12, not pumped.
[h] July 24, not pumped.
[i] March 15.

The following diagram, fig. 2, shows the relation that exists between the rainfall and developed water at Red Hills:

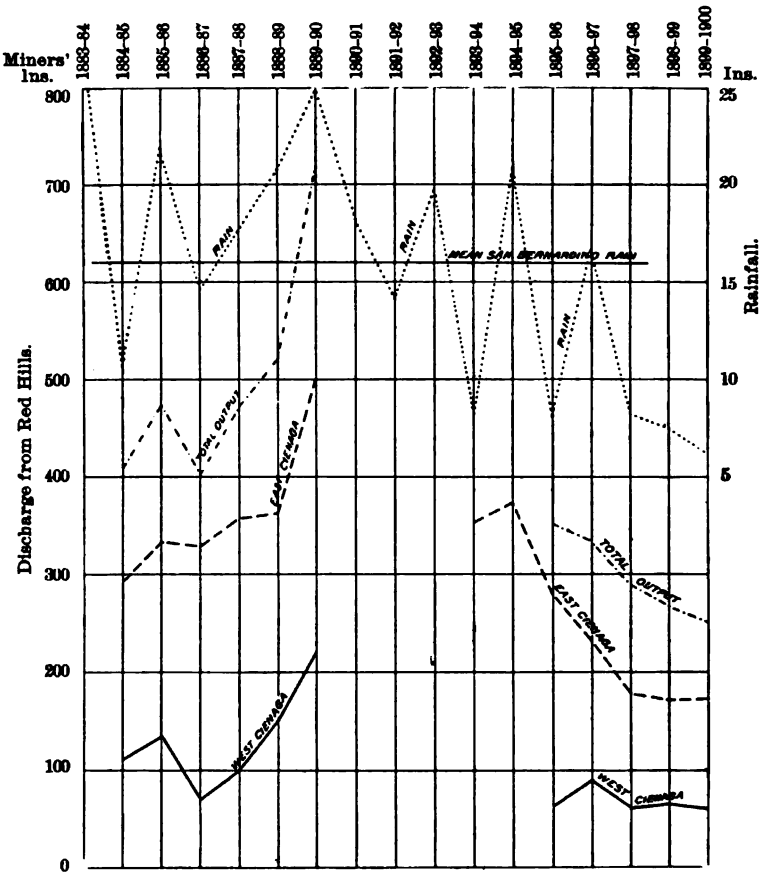


FIG. 2.—Diagram showing relation of rainfall to developed water at Red Hills. Dotted line shows rainfall, in inches, as measured at San Bernardino; dot-and-dash line shows discharge, in miners' inches, from all of the developments at Red Hills, exclusive of the Stowell wells; dash line shows discharge, in miners' inches, of east cienagas and Y tunnel, exclusive of Lone Star; heavy solid line at bottom shows discharge, in miners' inches, from 90-acre tract at west end of hill, exclusive of the Stowell wells.

From 1888 to 1900 many lineal feet of tunnels were run and numerous wells were sunk at the Red Hills for new water supplies, but in spite of this development the amount of water available materially diminished—from 406 miners' inches to 253 miners' inches. Although this decrease is influenced by the diminished rainfall during the period, it is improbable that all of the work performed resulted in much if any permanent benefit to the irrigators. The gravel beds above the Red Hills are much smaller than those above Colton, and consequently are more quickly drawn down. The chief question in situations of this kind is how large a water supply can be counted upon to recharge the underground reservoir. This can be determined by measuring the area of the tributary drainage basin from the topo-

graphic atlas sheets of the United States Geological Survey. To this area should be applied the mean annual run-off. In this case the mean annual run-off, in second-feet per square mile, can be obtained from a study of records of discharge of San Gabriel and Santa Ana rivers. The Red Hills are shown on the Cucamonga atlas sheet of the Geological Survey, and are 2 miles northeast of North Ontario.

Estimated monthly discharge of San Gabriel River and canals near Azusa.

[Drainage area, 222 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1895.						
September	39	29	32.0	1,928	0.16	0.14
October	32	27	29.0	1,811	.16	.13
November	50	29	40.0	2,392	.20	.18
December	57	37	42.0	2,561	.22	.19
1896.						
January	51	26	37.0	2,275	.20	.17
February	54	36	41.0	2,358	.19	.18
March	169	38	111.0	6,825	.58	.50
April	91	40	54.0	3,213	.28	.25
May	42	29	36.0	2,214	.18	.16
June	26	13	19.0	1,131	.09	.08
July	15	9	12.0	738	.06	.05
August	36	9	14.0	861	.07	.06
The year	169	9	39.0	28,307	2.39	.17
1896.						
September	18	11	13.0	774	0.07	0.06
October	188	10	24.0	1,476	.13	.11
November	40	15	19.0	1,131	.09	.08
December	37	17	22.0	1,353	.12	.10
1897.						
January	147	25	58.0	3,617	.29	.26
February	1,713	64	345.0	19,146	1.58	1.55
March	1,765	294	466.0	28,623	2.42	2.10
April	370	201	294.0	17,519	1.48	1.32
May	196	94	145.0	8,851	.75	.65
June	91	54	68.0	4,033	.34	.31
July	52	27	38.0	2,343	.20	.17
August	34	22	26.0	1,613	.14	.12
The year	1,765	10	126.5	90,479	7.61	.57
1897.						
September	23	18	21.0	1,226	0.10	0.09
October	1,640	22	91.0	5,595	.47	.41
November	34	31	33.0	1,860	.15	.14
December	34	28	31.0	1,875	.16	.14
1898.						
January	63	27	40.0	2,453	.20	.18
February	70	32	40.0	2,241	.19	.18
March	83	28	35.0	2,131	.18	.16
April	37	25	33.0	1,950	.17	.15
May	83	25	36.0	2,223	.19	.16
June	30	14	19.0	1,159	.10	.09
July	15	9	11.0	672	.06	.05
August	9	5	7.0	456	.04	.03
The year	1,640	5	33.0	23,841	2.01	.15
1898.						
September	10	6	8	467	0.04	0.04
October	10	8	9	533	.05	.04
November	11	8	10	580	.05	.04
December	18	12	14	832	.07	.06
1899.						
January	33	15	23	1,414	.12	.10
February	28	20	22	1,244	.11	.10
March	40	18	26	1,623	.14	.12
April	28	16	21	1,262	.11	.10

Estimated monthly discharge of San Gabriel River and canals near Azusa—Cont'd.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth in inches.	Second-feet per square mile.
1899.						
May	17	12	14	842	0.07	0.06
June	22	5	10	565	.05	.04
July	4	3	4	221	.02	.02
August	6	4	5	295	.03	.02
The year	40	3	14	9,878	.86	.06
1899.						
September	6	3	37	2,202	0.19	0.17
October	35	4	12	738	.06	.05
November	24	10	14	833	.07	.06
December	39	16	20	1,230	.10	.09
1900.						
January	89	22	32	1,968	.16	.14
February	23	18	20	1,150	.09	.09
March	30	16	20	1,230	.10	.09
April	26	13	17	1,012	.09	.08
May	86	16	37	2,275	.20	.17
June	22	8	15	893	.08	.07
July	10	4	6	369	.03	.03
August	5	4	4	246	.02	.02
The year	89	3	20	14,146	1.19	.09
1900.						
September	6	3	4	238	0.02	0.02
October	6	4	5	307	.02	.02
November	5,200	5	186	11,068	.93	.84
December	53	31	40	2,460	.21	.18
1901.						
January	1,450	28	169	10,391	.87	.76
February	2,605	137	696	38,654	3.27	3.14
March	440	135	221	13,589	1.15	1.00
April	130	95	110	6,545	.56	.50
May	272	83	121	7,440	.63	.55
June	93	41	63	3,749	.31	.28
July	41	24	30	1,845	.16	.14
August	27	15	20	1,240	.10	.09
The year	5,200	3	139	97,526	8.23	.63

Discharge measurements of mountain streams of San Gabriel Basin, 1898.

Stream.	Point of measurement.	Date.	Discharge.	Date.	Discharge.
			Sec.-feet.		*Sec.-feet.*
San Gabriel River	Power company headworks (includes developed water).	July 1	15.37	August 23	7.38
Dalton Canyon	In canyon			August 25	.05
San Dimas Canyon	do			August 26	.06
Sawpit Canyon	do	July 1	.34	August 23	.00
Total		July	15.71	August	7.49

Return waters of San Gabriel Basin near El Monte Narrows, 1898.

Stream.	Point of measurement.	Date.	Discharge.	Date.	Discharge.
			Sec.-feet.		*Sec.-feet.*
Whittier ditch	El Monte road crossing	July 3	1.83	August 31	1.80
Do	Pumping plant	do	1.40	do	1.40
Temple ditch	In narrows	do	9.06	do	6.88
San Gabriel River	First channel—Baldwin's road.	do	8.79	do	7.81
Do	Old channel—Baldwin's road	do	6.18	do	6.17
Do	Camper's station	do	3.36	do	.63
Puente ditch	San Gabriel Narrows	do	2.44	do	.00
San Gabriel River	Old Mission bridge	do	29.79	do	27.91
Total flow in narrows.		do	62.85	do	52.60
Mountain streams		do	15.71	do	7.49
Excess of return water.		do	47.14	do	45.11

For a description of the settlement of the San Bernardino and Redlands districts, see the Nineteenth Annual Report of the United States Geological Survey, Part IV.

RIVERSIDE DISTRICT.

HISTORY.

The first irrigation movement in the Riverside district was made by the Silk Center Association in November, 1869. This was a colonizing enterprise for the production of raw silk. Arrangements were made for the purchase of 5,000 acres of land from the Jurupa and Rubidoux ranchos, and 1,400 acres of Government land were occupied under the United States land laws. The town of Jurupa was started on these lands, the name being changed in 1870 to Riverside. This association filed the first water notices for the settlement and began the construction of a canal in 1870. Silk culture was abandoned the year that the movement was initiated. New parties allied themselves with the colonizing movement, and the Southern California Colony Association was founded, with Judge J. W. North, president; Dr. J. P. Greves, secretary; Dr. K. D. Shugart, treasurer; and Mr. T. W. Cover, superintendent. Construction of the canals was begun in October, 1870. The first canal was built during the winter of 1870–71, on a grade of 1 inch to 100 feet, from a point on the south or left bank of Santa Ana River about 2 miles below Colton. The total length was 13.5 miles. It was 8 feet wide on the bottom, 12 feet wide on top, and 3 feet deep; the alignment and grade were very irregular. It had a capacity of a little more than 700 miners' inches (14 second-feet) down to the Spanishtown flume, and 500 to 600 miners' inches (10 to 12 second-feet) below that point. The conduit to the Pachappa Arroyo cost from $50,000 to $60,000. During the fall of 1871 this ditch was extended to Terquisquite Arroyo. By 1875 the ditch had been improved so that it carried 1,000 miners' inches (20 second-feet), but at that time not more than 500 acres were irrigated. This is now known

as the old upper canal of the Riverside Water Company. The diversion is by means of a brush dam, and the conduit is wholly in earth. There are no engineering features of interest.

In 1874 S. C. Evans, of Fort Wayne, Ind., and W. F. Sayward, of San Francisco, purchased 8,000 acres of land adjoining Riverside and united with the owners of the San Jacinto Sobrante Rancho, which is situated still farther to the south, to construct another canal from Santa Ana River for the irrigation of their lands. The former of the proposed settlements was called the New England Colony and the latter the Santa Ana Colony. The Southern California Colony Association began suit to prevent the construction, which had been already started, of the new canal across their lands. The dispute was ended by the New England and Santa Ana colonies purchasing, in May, 1885, a four-sevenths interest in the original association for the sum of $50,000. In April, 1875, the Riverside Land and Irrigation Company was organized by the members of the three original colonies or companies, and by March, 1877, this new company had absorbed all of the land and water holdings of its predecessors. In 1876 the new or lower canal of the New England and Santa Ana colonies was completed, at a cost of $120,000, and during the season about 2,000 acres were irrigated by the two canals. In July, 1879, the Riverside Canal Company, which was organized for the purpose, purchased all of the water rights and conduits of the Riverside Land and Irrigation Company, the latter receiving as compensation all of the capital stock of the new company. The value of each share was placed at $20, and 20,000 shares were issued. It was further agreed that the stock should be adjusted so as to correspond with the number of acres for which water was obtained. The avowed original intention of the company was to have each share of stock cover a particular acre irrigated; but the sale of stock in some instances was made to persons who had not bought land from the company but had obtained it from the Government. By this method of disposing of the stock of the canal company those originally in power found that they would soon lose control, and therefore they passed new resolutions, assigning two shares of stock to each remaining acre, the canal company holding the shares at a par value of $10 each, one share to be issued with each acre of land and the other share to remain in the hands of the company until it had sold the majority of its lands, when the landowner could at his option purchase it at the original price.

The purpose of the Riverside Land and Irrigation Company was primarily to promote the sale of its irrigated lands. As their affairs progressed and the lands were sold the company naturally desired to continue its benefits by handling the waterworks of the irrigators and by expanding its water rights over more lands. Water rates were advanced from $1.92 an acre, in 1878, to $2.23 an acre, in 1881. These movements on the part of the company were naturally opposed by the

irrigators, and a protracted struggle ensued. The irrigators organized the Citizens' Water Company with which to battle for their claims. About this time a State law was passed giving the county boards of supervisors the right to regulate water rates and compelling the continued delivery of water at uniform rates to irrigators to whom water had previously been sold. The Riverside Canal Company claimed that it had the right to charge such rates as would insure the maintenance of its plant and interest on the investment and to charge a bonus of $20 to landowners holding no stock. To this the irrigators replied that the original investment had been more than returned to the Riverside Canal Company from the sales of its irrigated lands. The courts, as is usual in cases of this nature, were slow and indecisive in their judgments. This dispute, which we see repeated in every irrigation locality, lasted from 1882 to 1885 and ended in the Holt compromise. By this agreement the Riverside Water Company was organized by the irrigators to deal in all classes of water property. They issued 24,000 shares of stock covering certain specified lands, to be an appurtenance thereof, two shares to apply to each acre, and afterwards to be transferable only with the land. Shares were issued for 6,000 acres of land then irrigated, and another 6,000 acres were specified for which water could be sold as a surplus was developed. This unirrigated land belonged to the old Riverside Land and Irrigation Company. It was transferred to the new company, called the Riverside Land Company, and one-half of the stock was issued to the Riverside Water Company and one-half to Evans and Felton, the latter the controllers of the old Riverside Land and Irrigation Company and the Riverside Canal Company. The Riverside Water Company paid to the Riverside Canal Company $70,120 in bonds and exchanged stock of the old company for stock in the new at the rate of two shares of the old stock for one share of the new. The cost of the purchase to the new company was about $120,000. Residents within the prescribed limits who did not own canal company stock were permitted to purchase it at the rate of $10 a share, two shares to the acre. The irrigators thus control the Riverside Water Company, elect their officers, and determine their own water rates. This method of management has proved successful, while both corporate and irrigation districts have been continuously unsatisfactory. It is an interesting fact that no definite decisions were reached through the courts, but that settlements were the result of compromise. The Riverside Water Company now successfully operates the plant. It delivers water to the stockholders at cost, and has improved and extended its works by the sale of bonds secured by the property of the corporation and its stockholders.[a]

[a] The foregoing historical statement is largely obtained from Irrigation in Southern California, by William Ham. Hall, State engineer, 1888.

The general development of the Riverside district is shown in the following table:

Table showing commercial growth of Riverside.

Year.	Population.	Orange shipments.	Assessed valuation.	Post-office receipts.
		Carloads.		
1887		375	$3,586,933	$4,044
1888		725	3,978,099	10,288
1889		982	4,418,035	10,198
1890	4,682	1,500	4,588,890	11,591
1891		1,446	4,830,575	14,262
1892	7,395	2,100	5,834,000	15,458
1893		2,526	5,392,351	16,764
1894		1,928	4,958,247	16,243
1895		2,800	4,437,004	14,085
1896		2,018	4,588,181	14,147
1897	8,000	2,508	3,875,236	15,143
1898		4,000	[a] 4,984,565 [b] 2,038,003	16,513
1899		2,048	[a] 5,123,045 [b] 3,012,753	16,555
1900		[c] 3,799 [d] 4,300	5,499,895	19,336

[a] City valuation. [b] County valuation. [c] To date. [d] Estimated.

The city has two banks of deposit, one savings bank, thirteen churches, and eight schoolhouses. It has a debt of $120,000, and the tax rate is 65 cents on the hundred dollars. The ratio of its bank deposits and assessed valuation to its population makes it probably the first city in per capita wealth in the United States. The city covers 56 square miles, the corporate limits being extended to the outlying lands, largely for the purpose of local water and horticultural control. In June, 1893, it became the county seat of the newly formed county of Riverside.

The canals of the Riverside Water Company cover 12,000 acres of land, of which 8,500 acres are now being irrigated. The remaining 3,500 acres are to be sold and improved. The main canals aggregate 36 miles in length, while the lateral pipes, the flumes, the cemented and open ditches for distribution exceed 150 miles in length. Water is conveyed direct to every subdivision of the 8,500 acres under the irrigating system.

RIVERSIDE WATER COMPANY.[a]

WATER SUPPLY.

The Riverside Water Company obtains its supply from Warm Creek, from Santa Ana River, and from artesian wells.

Warm Creek has its source in San Bernardino Valley, 3½ miles east of the town of San Bernardino, and is fed entirely by springs and return water along its course. The flow is uniform, being about 80 second-feet during the irrigating season. It has no defined surface connection

[a] The writer is indebted to Mr. Kingsbury Sanborn for most of the information contained herein regarding this company.

A. HEADWORKS OF RIVERSIDE CANAL IN WARMSPRINGS CREEK.

B. HEADWORKS WEIR OF RIVERSIDE WATER COMPANY.

with the mountain drainage line. Its source is largely near Harlem Springs, about 4 miles east of the city of San Bernardino.

The surface water of Santa Ana River is all diverted near the mouth of its canyon above Redlands, and for miles the bed of the stream below that point is totally dry during the irrigating season, but gradually the underflow comes to the surface at points south of the town of San Bernardino, and uniting with the return waters from irrigation on the mesas on the north side of the river amounts to 8 second-feet and becomes a valuable adjunct to the Riverside Water Company's supply.

The artesian wells of the Riverside Water Company are located on several tracts of land, all situated in San Bernardino Valley east of Colton, San Bernardino, and the dike previously referred to. They vary in depth from 68 feet to 590 feet, and in diameter of the casings from 6 inches to 11 inches. The largest is a 9-inch well near Harlem Springs, 594 feet deep and flowing, on August 26, 1898, 3 second-feet of water.

The distinctive feature of the water supply of the Riverside Water Company is its constancy. Warm Creek is the principal source of supply. The volume that is available at the headworks of the canal (see Pl. IX) remains practically constant, winter and summer, dry years and wet years, except when the unusual floods from the mountain basins are projected far out into the valley, flowing continuously through to the narrows. As has previously been explained, the supply is largely regulated in the underground reservoirs of the valley. The point of diversion being at the lower level of the reservoir insures a continuous flow, even during dry years. The driest cycle of seasons of which there are records of stream flow is the five last past, and it is claimed by the water company that its supply was equal to the normal during the summer of 1898. On June 30, 1898, there were flowing in the canal at the old Colton mill, above all diversions, 3,473 miners' inches (69.46 second-feet) of water. This is considered a normal summer flow from the various sources of supply.

Construction of the Davis well, which was leased by the owner, Capt. Louis S. Davis, to the Riverside Water Company for the season of 1899, was started April 27, 1899. The well was completed May 12 of the same year. It is 510 feet in depth, has a 10-inch pipe, a No. 12 iron casing, and the same size all the way down. The cost was $804. The water all comes from the bottom of the well. When first finished it rose 34 inches above the top of the casing, and by weir measurement amounted to 350 miners' inches. The well is located in the northeast corner of lot 17, block 44, of the 12-acre survey of the San Bernardino Rancho. On October 2, 1899, it was flowing, by weir measurement, 233.7 miners' inches.

On April 3, 1900, the Riverside Water Company was successful in obtaining another large flowing well in San Bernardino County, the

water in which rises 12 inches above the casing. The well yields more than 150 miners' inches, making it the second largest well in San Bernardino County. It is located near the Davis well. The strike came at a particularly opportune time, as Captain Davis refused to lease the Davis well to the water company this year (1900), and the water was shut off from the Riverside ditches about April 1, 1900. The strike was made at a depth of 540 feet. This well is the fourth in the district that is now flowing more than 100 miners' inches. The Riverside Water Company has a large tract of land in line with these wells.

MAIN CANAL.

The main canal of the Riverside Water Company has a capacity of 100 second-feet. It diverts water from Warm Creek, a half mile east of the town of Colton and just above the junction of Warm Creek with Santa Ana River, by means of a well-constructed brush dam. The canal follows along the west or right bank of Santa Ana River for a quarter of a mile. At that point a 6-foot drop is made through a turbine wheel which develops about 25 horsepower during the dry summer months. This power is used to pump 104 miners' inches (2.08 second-feet) of developed water from a pit and trench extending into and across the sandy bed of Santa Ana River. From this drop the water enters a cement-lined canal. Thence it crosses the Santa Ana in a substantial redwood box flume about 1½ miles long, supported the entire distance upon piling. (See Pl. LXIII, *B*, of the Twentieth Annual Report, Part IV, p. 554.) The flume box is 8 feet wide, 4 feet deep, and on a grade of 26 feet above the bed of Santa Ana River in the highest place. After crossing the river the water enters a 60-foot tunnel, then a short stone ditch, and finally the long tunnel, which is 3,250 feet in length, 7 feet and 8 inches wide at bottom, 8 feet and 4 inches wide at the 4-foot mark, and 6 feet high. The top of this tunnel is roofed with heavy timbers covered with redwood lagging and resting on brick piers laid in pure cement. The bottom and the walls between the piers are made of well-rammed concrete, the whole being covered with a coating of pure cement. After the water leaves the tunnel in its course toward Riverside it makes a drop of 40 feet at Highgrove and furnishes, from a Stillwell & Bierce turbine, 250 guaranteed theoretical horsepower, which is now used by the San Bernardino Electric Light and Power Company to develop electricity, which is supplied to Colton and San Bernardino for illumination and power purposes. At Riverside the upper canal is connected with the lower canal by a 32-foot fall, which furnishes power to the National Ice Company for the manufacture of ice. The canal runs through the city of Riverside, making four more drops before it reaches its destination in the Temescal Wash.

A. LINING RIVERSIDE WATER COMPANY'S CANAL WITH CEMENT PLASTER.

B. CEMENTED CANAL OF RIVERSIDE WATER COMPANY.

Owing to the loss of water by seepage and evaporation during the hot summer months of the irrigating season, and to save the expense of cleaning vegetation from the canals, it has been found economical to plaster the banks (see Pl. X). The usual method followed is to first thoroughly wet the canal, when dry, by building earth dams at intervals which will bring the water as near the top of the canal as possible. The water is allowed to soak into the ground and the remainder is drained off. After the canal has again become dry enough to work it is excavated to a subgrade three-fourths of an inch outside of the section of the bank and below the true grade. The lining is extended on each side of the top of the bank for a distance of 5 inches and a depth of three-fourths of an inch. Just before plastering, the banks of the canal are thoroughly wet, by spraying or sprinkling. The cement mortar, which is applied to a depth of three-fourths of an inch, is composed of one barrel of pure Portland cement to four barrels of clean, sharp sand thoroughly mixed dry on a floor, after which sufficient water is added to moisten to the proper consistency and the whole is again thoroughly mixed. The canal is first plastered on the sides and a selvage of 5 inches is built on each side of the top; the bottom lining is put in last. It is finally completed by washing with two coats of liquid cement. After the cement mortar is in place the canal is kept moist for six days, so that it will harden with uniform color.

MEASUREMENT OF WATER.

An important detail in connection with this canal system is the measurement and division of the water. Near the head of the main canal, where it crosses the Southern Pacific Railway's main line to Yuma, is a weir which measures the greater portion of the water diverted by the company. A device of local origin has been constructed for permanently recording the discharge over the weir. It is made in Riverside, by Mr. C. H. Watson, and costs, set up, about $50, or $40 in the shop.

AUTOMATIC WATER REGISTER.

This is a register for recording accurately the elevation of the surface of water in either a reservoir or a flowing stream. It consists of an upright revolving cylinder the motion of which is regulated by clockwork, covered by the record sheet of paper, which is ruled in vertical lines, each space representing one hour of time, and in horizontal lines measuring the elevation, which is marked upon the record sheet by a pencil fixed upon an upright rod terminating at its lower extremity in a float resting in the water. The register is inclosed in a substantial wooden box or case 45 inches in height, 17 inches in width, and 12 inches in depth, which is provided with a secure lock. The rod extending from the recording pencil to the float passes through the

bottom of the box, and the float rests in a well of still water so connected with the main body of water as to maintain the same elevation of surface as the main body and still be free from wave motion and the effects of currents. The float is so weighted as to be steady in the water, and by the direct action of the rod it imparts to the recording pencil firmness and accuracy.

The register described, which is the size generally used to record the fluctuations of streams running over weirs and to measure in that way the volume of water in ordinary streams, has a cylinder which will record a rise or fall of 22 inches and upon one record sheet show the exact elevation of the water surface each hour for an entire week, at the end of which the clock must be wound and a new record sheet be placed upon the cylinder. The same record sheet can, however, be made to do service for four or five weeks by changing the elevation of the pencil at the beginning of each week and noting its relation to the datum. A telescoping arrangement of the float rod provides for this.

The revolution of the cylinder is produced by means of a cord passing over a small pulley at the end of the cylinder. This cord, which is treated so as to be unaffected by moisture, also passes over a pulley upon the spindle of the clock, and terminates at each end in a metal weight. These weights are so adjusted that the heavier one provides all the power to revolve the cylinder, the motion of which is steadied by the lighter weight and accurately regulated by the movement of the clock.

The recording pencil may be either an ordinary lead pencil or a pen. It is gently pressed upon the recording cylinder by an ingenious contrivance consisting of an arm or spring, and can be set back from the cylinder when necessary to change the record sheet.

This register is in use on many streams and by many water companies in southern California.

The water for irrigation is delivered, by means of vitrified pipes, to a small bay, from which it passes over a weir to the orchard lateral. A gate, known as the Watson gate, which is cheaply constructed and easily handled is inserted in the discharge pipe from the canal and set so as to give the desired head on the weir of the lateral. For a description of this gate see paper entitled Water Supply of San Bernardino Valley, in the Nineteenth Annual Report of the United States Geological Survey, Part IV, pages 595 to 596.

The constancy of the volume of the supply of water in this locality is particularly favorable to the use of these devices, which are local developments.

SALE AND DISTRIBUTION OF WATER.

The water is conveyed, by means of pipe lines and cement and earthen ditches, to the highest corner of each 10-acre lot. Irrigation water is sold for 15 cents a miners' inch (0.02 second-foot), twenty-four hours' run. The quantity that an irrigator may use is not limited. One miners' inch flowing twenty-four hours is equal to 12,925 gallons. When the water is piped under pressure and not measured it is sold at the rate of $10 an acre for the season, unrestricted service.

To 1899 the Riverside Water Company's irrigating system is said to have cost $837,757.83 and its domestic system $168,181.80. The following is the annual statement of the secretary of the company on December 1, 1899:

Assets.

Irrigating plant, value December 1, 1898		$822,118.28
Improvements, 1899:		
Cooley water right	$4,006.40	
Zanjero houses	71.95	
Telephone (construction)	184.50	
Lateral ditches	336.84	
Pipe laterals	2,315.16	
Engineering	350.81	
Storm ditch	700.30	
Artesian wells	5,097.98	
General improvements	2,575.61	
		15,639.55
Value of plant December 1, 1899		837,757.83
Domestic system, value December 1, 1898	167,496.70	
Improvements, 1899	685.10	
		168,181.80
Furniture and fittings		1,144.07
Rubidoux hotel site		1,000.00
Sinking fund		33,028.00
Live stock		863.25
Stock of Riverside Land Company		109,344.11
Due from domestic water users		2,452.44
Due from Riverside Land Company		13,315.23
Tools		7,432.61
Solvent accounts due		744.94
Cash on hand and in bank		7,032.68

Operating expenditures.

Legal expense	$2,452.00
Telephone (operating)	395.84
Bond expense	583.11
Cook ranch	561.80
Interest on bonds	33,221.53
Interest and exchange	54.31
Taxes	6,313.17
Printing	125.00
Advertising	66.38

Stationery	$59.72	
Breaks in canals	107.95	
Repairs	4,938.25	
Salaries	5,757.00	
Cleaning canals and laterals	4,082.10	
Expense (office rent, etc.)	654.94	
Night watch	90.20	
Zanjero wages	5,097.15	
Domestic water salary	1,200 00	
Feed	462.15	
Postage	186.50	
Pipe repairs	274.64	
Temporary water leased	3,459.14	
		$70,142.88
Total		1,252,439.84

Liabilities.

Capital stock	236,380.00
Bonds payable in 1912	812,500.00
Dividends (from land company)	20,000.00
Loss and gain	86,058.77
Accounts payable	62.50

Operating income.

Ranch	$1,897.32	
Water sales by the inch	59,454.10	
Water sales by the acre	5,673.60	
Water power	4,891.65	
Domestic water	24,662.65	
Rent	859.25	
		97,438.57
Total		1,252,439.84

The receipts of the company for water service are shown in the following table:

Receipts of Riverside Water Company for water service.

Year.	Irrigating system.	Domestic system.	Year.	Irrigating system.	Domestic system.
1886	$21,418.81	$120.10	1893	33,884.91	23,151.10
1887	24,919.47	1,658.95	1894	40,738.80	22,284.60
1888	23,830.44	3,672.30	1895	33,504.43	22,362.43
1889	26,394.16	9,525.00	1896	35,277.05	22,463.76
1890	33,516.00	13,058.45	1897	49,725.88	21,719.60
1891	37,421.45	19,209.83	1898	52,282.93	23,972.01
1892	39,557.10	22,349.30	1899	65,127.70	24,662.65

The capital stock of the Riverside Water Company is $240,000, divided into 24,000 shares of $10 each, intended to cover 12,000 acres, two shares of stock being issued for each acre of land. Of this entire capital stock, to December 31, 1899, there had been paid in and stock issued for $236,380, or 11,819 acres. The amount of cash expended by

the company to that date was $1,252,439; the value of the plant is estimated at $2,500,000. The amount expended annually since its organization, in purchase and construction, is shown by the following table:

Annual expenditures of Riverside Water Company in purchase and construction.

1885	$120,000.00	1893	$84,583.91
1886	27.00	1894	73,267.72
1887	598.56	1895	16,049.32
1888	64,657.28	1896	11,404.47
1889	311,962.02	1897	9,681.32
1890	41,362.22	1898	18,255.85
1891	178,666.59	1899	16,324.65
1892	59,118.72		

Water rates fixed by the board of city trustees of Riverside.

1885 to 1888, inclusive, 7½ cents for 1 miners' inch, 24 hours' run.
1889 to 1897, inclusive, 10 cents for 1 miners' inch, 24 hours' run, or $7 per acre per annum, unlimited service from pressure pipes.
1898 to 1900, inclusive, 15 cents for 1 miners' inch, 24 hours' run, or $10 per acre per annum, unlimited service from pressure pipes.

DOMESTIC SYSTEM.

Water for municipal and domestic purposes was at first obtained from the irrigating canals; but in 1886 the Riverside Water Company began the construction of its domestic system, by which artesian water for municipal and domestic uses is delivered through a well-conceived and comprehensive pipe system, under a pressure of not less than 70 pounds to the square inch. The capacity of the system is 3,000,000 gallons daily. The water supply is from eighteen artesian wells located in lot 4, block 65, San Bernardino Rancho, about 2½ miles east of the town of Colton. The wells vary in depth from 111 feet to 344 feet, and cost, on an average, $500 each.

In the fall of 1887 the first group, consisting of six 11-inch wells, were sunk to an average depth of 115 feet, and flowed, when finished, about 5 second-feet. These wells were sufficient to supply the domestic consumption of Riverside for several years; but as the demands for water increased the company found it expedient to construct more wells, which they did, using casings of smaller diameter and sinking the wells deeper in order to tap lower subterranean strata. The water from all of these wells is conducted through a gravity vitrified pipe line to a circular cement-lined reservoir, where it is aerified over a partition. (See Pl. VI, *B*.)

From the reservoir the water passes through three screens, of different size mesh, to a 17-inch steel pipe. Pipe of this size extends for a distance of 3.8 miles, when it is reduced to 16-inch steel pipe for the remainder of the distance (4.3 miles) to Riverside. The pipe line has a total fall of 172 feet to the center of the city of Riverside, and a capacity of 3,900,000 gallons daily. In the city the larger mains—6-inch, 8-inch, and 9-inch—run east and west and are connected

at intersecting streets with smaller pipes. The fire hydrants are attached to the large mains and afford excellent fire service.

GAGE CANAL SYSTEM.*

The Gage canal is in Riverside and San Bernardino counties. Its initial point is in the bed of Santa Ana River, in lot 4, block 69, San Bernardino Rancho; or a more specific description would be SW. ¼ sec. 13, T. 1 S., R. 4 W., S. B. M. The initial point has an absolute elevation above sea level of 1,035 feet. The terminal point of the canal is at the south boundary of SE. ¼ sec. 19, T. 3 S., R. 5 W., S. B. M. The total distance between the two points, following the line of the canal, is 20.16 miles. The construction of the canal proper was begun in the year 1885 and was finished as far as flume No. 9, over Terquisquite Arroyo, in the year 1886. The actual work of construction of the remaining portion was begun in the spring of 1888 and was practically completed during that year. The whole of the canal was excavated, generally in the clay formation, on a grade of 2 and 3 feet to the mile, and to a uniform depth of 4 feet, with varying width of bottom.

The accompanying map (Pl. I) shows the location of the canal in relation to all of the intermediate points and the adjacent territory.

Pls. VII, *A*, and XI, and figs. 3 to 14, inclusive, show features of the system.

HISTORY.

The construction of the Gage canal was begun by Mr. M. Gage in the year 1885, and was finished so that water was run through it as far as Terquisquite Arroyo in the fall of 1886. During the winter of 1886–87 all of the tunnels were thoroughly cemented on the sides and bottom, to a depth of from 4 to 6 inches, with Portland cement concrete, and their tops were timbered.

Up to that time the work was under the supervision of C. C. Miller, as engineer, and R. Gage, as superintendent of construction. On January 18, 1887, W. Irving took charge of the work as engineer, Mr. Gage remaining as superintendent of construction.

During the early part of the year 1887 a temporary connection was made between the head of the canal and the river, and water was run continuously to East Riverside in quantities varying from 300 to 500 miners' inches, as the demands of the owners of the land required.

The average grade of the canal between the head gates and Terquisquite Arroyo is about 2¼ feet to the mile, and the total distance 11.9 miles. During the spring of 1887 a survey of the continuation of the canal below Terquisquite Arroyo was made by W. Irving, the trial line being run and general location determined on or about March 15 of that year. The grade on which the continuation was made was about 2 feet to the mile, or about 0.04 foot to the station.

*The writer is indebted to Mr. William Irving, of Riverside, for most of the facts herein contained regarding the Gage canal.

A. WELL NO. 43 OF GAGE CANAL SYSTEM.

B. METHOD OF CAPPING ARTESIAN WELL OF THE GAGE SYSTEM.

On August 1, 1887, the permanent head gates were located and the work of construction was begun. In November, 1887, the water was turned into the canal through the new head gates, which are shown in fig. 3, page 86. In fig. 4, page 87, is shown a section of the headworks.

On August 15, 1887, the work of constructing a submerged dam for the diversion of water to the canal and for carrying the water from the sources on the north side of the river was begun, the dam being completed about the end of November of that year.

In the same year Mr. M. Gage claimed to be the owner of all of the water flowing in Santa Ana River at the point of diversion, which at that time was said would equal, on an average, about 450 miners' inches, or 9 cubic feet per second, during the irrigation months. At the same time Mr. Gage had developed, by means of fourteen artesian wells, about 600 miners' inches, as measured by G. O. Newman, making a total of 1,050 miners' inches, or 21 cubic feet per second. The owners of the Gage canal bought the Camp Carlton ditch, one of the old water rights of Santa Ana River, upon the ownership of which it based in part its claim to the total flow of the river at its headworks. In consideration of this transfer the vender was to receive water from the Gage canal.

At that time Mr. M. Gage was the owner of all of the lands known as the Orange Grove Homestead, amounting to about 2,300 acres and situated in and forming part of the San Bernardino Rancho. Santa Ana River flows through these lands for a distance of about 3½ miles, the course of the river being S. 65° W., on a line passing through points of entrance and exit. The lands described form both banks of the river throughout very nearly its entire course. In consequence, Mr. Gage, as riparian owner, claimed all of the water flowing in the river at that point. About the end of June, 1887, the Riverside Water Company entered suit against him, denying his right to take more than a certain amount of water from the river. The case was tried, and the judgment, which was given in the early part of 1888, limited the amount of water to be taken from the river by Mr. Gage during the irrigation season—including the months of May, June, July, August, and September—to 289.5 miners' inches. Under that decision it is presumed that during the remaining seven months all of the water flowing in the river may be taken out and used by those who can obtain it.

In the spring of 1888 the total available supply to the Gage canal was as follows:

	Miners' inches.
River water	289.5
Parish ditch, say	30.0
From wells	600.0
Total (1887, 1888)	919.5

Or 18.39 cubic feet per second.

During a flood in Santa Ana River in the month of February, 1888, the submerged flume was carried away, and up to the present time it has not been replaced.

In the latter part of 1887 and the early part of 1888 the portion of the canal below Terquisquite Arroyo was finally located, the terminal point being on the SE. ¼ sec. 19, T. 3 S., R. 5 W., S. B. M., 8.26 miles distant from the terminus of the upper section, measured on the line of the canal. This makes a total length of canal equal to 20.16 miles between the head gates and the lower end, or the point above described.

The work of construction on the second or lower section of the canal was begun in the early part of the year 1888, Grant Brothers having the contract for the earth work. Flumes Nos. 9 to 13, inclusive, were constructed by Mr. M. Gage, under the supervision of W. Irving, as engineer, and R. Gage, as superintendent of works, and the whole was practically completed in the early part of August of the same year (1888), except a short interval (about 1,700 feet) through sec. 21, T. 3 S., R. 5 W., S. B. M.

On March 31, 1888, the water was first turned into flume No. 9, over Terquisquite Arroyo, and from thence over to flume No. 10 and into the canal below for a distance of about 600 feet. After that date it was run to section 21, as already described. The amount of water running in the Gage canal during the month of July, 1888, was from 500 to 700 miners' inches, measured at flume No. 3, which was used for the irrigation of lands north of Terquisquite Arroyo, a portion of the water wasting at flume No. 11, Arlington Heights.

During the year 1888, commencing about the month of April, a number of wells were sunk in the river bottom near the point where Mountain View avenue crosses the river. This group of wells was known then and for sometime afterwards as group E. They were eleven in number, including two wells excavated in 1887 a short distance west of the avenue, the remaining nine being located east of the avenue, seven of them on the south side of the river and two on the north side. This group (E) of wells was redesignated in 1892, and they are now known as wells Nos. 28 to 38, inclusive, and form part of a general numbering (1 to 55) of all the wells tributary to the canal. They all are 10 inches in diameter, and at the time of excavation Nos. 28, 29, 33, 34, and 35 gave a very large flow and added greatly to the water supply. The combined flow of the eleven wells equaled 677 miners' inches.

During the year 1888 three additional wells were excavated on the east bank of the canal between flume No. 1 and the point where the Santa Fe Railroad crosses the canal. These wells are 10 inches in diameter. They formerly were known as part of group B, but now are known as Nos. 7, 8, and 9. They have added about 120 miners' inches to the general supply. At the end of the year 1888 the total

water supply available was equal to about 1,500 miners' inches, as follows:

	Miners' inches
Group B (Nos. 7, 8, 9, 11, and 12)	250.0
Group C (Nos. 45, 46, 47, 48, 49, and 50)	258.0
Group D (Nos. 51, 52, 53, and 54)	45.0
Group E (Nos. 28 to 38, inclusive)	582.5
Parish ditch	75.0
River water	289.5
Total	1,500.0

or 30 cubic feet per second.

During the year 1889 the Gage canal below Terquisquite Arroyo was completed in all of its parts and the water was run to the lower end. Improvements all along the line between the head gates and the terminus were made to grade by releveling, cutting, and filling, by increasing the strength of banks in the fills and wherever else needed, and by relining the flumes to grade where they had settled on their foundations.

The maintenance of the canal was under the supervision of Mr. M. Gage, represented by Mr. Irving, as engineer, and the expense was borne by Mr. Gage, excepting the portion between tunnel No. 13 and Terquisquite Arroyo, which was partially borne by the East Riverside Water Company. Many serious breaks occurred during the year 1889, causing several days' interruption in irrigation and considerable expense for repairs.

The total cost of construction of the portion of the canal south of Terquisquite Arroyo, including flumes Nos. 9, 10, 11, 12, and 13, was $30,250.73, as follows: Cuts and fills, $14,849.81; flumes (2,750 feet), $13,900.92; engineering, $1,500. Total length of canal, 8.22 miles.

During the months of June and July, 1889, Mr. E. Low planted to orange trees the greater portion of the south-central 80 acres of sec. 35, T. 2 S., R. 5 W., S. B. M. On this land was used, in 1889, the first water from the Gage canal below flume No. 9 for a useful purpose.

During this and the previous year the lands of Arlington Heights were platted in a most thorough manner by Messrs Whitten and Rawson, under the supervision of Mr. Irving, the street divisions generally inclosing 40 acres and the block thus formed being subdivided into 10-acre lots. All acreage is exclusive of streets.

During the early spring of 1889 one more well was sunk, forming part of group B and now known as No. 10 in the general numbering.

On April 17, 1889, by request of the Home Life Insurance Company, of San Francisco, Prof. E. W. Hilgard, of the University of California, made an examination and measurement of all water flowing or possible to flow at that date from the water sources of the Gage canal. The following are the results of the measurements made while all of the sources were flowing simultaneously and had been flowing for about thirty-six hours. The designation of the wells which was adopted by

Professor Hilgard was the letters A, B, C, and D for certain groups of wells which afterwards were known as B, C, D, and E, the A in the latter enumeration representing the Hunt & Cooley wells, in which Professor Hilgard was not interested. In the following enumeration the latter designation has been adopted, making it agree with all of the other references, to which will be added the present numbering:

	Miners' inches.
Group B, or Nos. 7 to 12, inclusive (6 wells)	260.0
Group C, or Nos. 45 to 50, inclusive (6 wells)	225.0
Group D, or Nos. 51 to 54, inclusive (4 wells)	35.0
Group E, or Nos. 28 to 38, inclusive (11 wells)	571.0
Parish ditch	157.0
South side streams (estimated)	75.0
Water right in Santa Ana River	289.5
Total	1,612.5

On July 27, 1889, by request of the Riverside Water Company Mr. G. O. Newman, representing that company, and Mr. Irving, representing Mr. M. Gage, examined for the first time since the decision of the court was rendered the diversion of water from the river through the Gage canal. They measured the total flow in the canal on the weir at flume No. 3 and determined the net product to be 746 miners' inches.

	Miners' inches.
Wells of group E (Nos. 1, 2, 3, 4, 6, 7, and 8, or, according to the present numbering, Nos. 38, 37, 36, 35, 33, 32, and 31) total discharge	320.0
Water right in river	289.5
Parish ditch (estimated)	120.0
Total water flowing at head gate	729.5
Measured water flowing into head gates over weir	594.0
Balance unused	135.5

The difference between the amount of water at the head gates and that at flume No. 3 is accounted for by the discharge of the wells of group B below the head gates. On July 26 or the day previous there was a larger quantity of water discharging into the canal at the head gates, as shown by the following:

	Miners' inches.
Water right in river	289.5
Product of seven wells	300.0
Parish ditch	140.0
Total at lower weir	729.5
Deduct amount at head-gate weir	679.0
Balance unused	50.5

The flow of water in the canal during the year 1889 varied from a maximum of about 800 miners' inches in July to about 500 miners' inches in November.

During the year 1890 many changes and improvements were made in connection with the canal and the lands of Arlington Heights. Mr. Gage had visited England in the fall of 1889, and had interested capitalists in his enterprise of developing the lands at Arlington Heights. In furtherance of the project two representatives, Messrs. T. Waterhouse and Wilson Crewdson, were sent by them to Riverside to examine the property. Their report being favorable a company was formed, the capital stock of which was placed at $1,255,000, divided into 5,000 A shares of $250 each and 1,000 B shares of $5 each. On December 13, 1889, a provisional contract was entered into between Messrs. M. Gage and Wilson Crewdson, which was assigned to the new company, known as the Riverside Trust Company, Limited.

During the early part of the year 1890 pipe lines of riveted steel plate were laid on Adams and Jane streets, and substantial bulkheads were constructed in the canal where the pipe lines entered. A vitrified pipe line similarly connected was laid on Evans street as far as Dufferin avenue. During the fall and winter following the canal was lined with masonry at the lower fill, between Harrison and John streets, and at flumes Nos. 13, 12, 11, 10, and 9. Retaining walls of masonry were also constructed at the ends of all of these flumes, thus removing the woodwork from contact with the clay. In addition to this the fill at Hall's reservoir and Eighth street, north of Terquisquite Arroyo, was lined with masonry and cement plaster.

A portion of the Williams tract lying east of the east and north line of the bluff of Santa Ana River, amounting to about 430 acres, was purchased by the Riverside Trust Company, Limited, in 1890. This purchase extended the frontage on both sides of the river 1 mile farther to the east, thus making a continuous frontage due east-west of 4 miles, or by following the course of river about 4¼ miles.

During the year it was determined to construct a levee on the south side of the river, beginning at the head gates and extending east, and in connection therewith to construct a flume immediately behind it for the conveyance of water from the artesian wells, and if thought necessary to carry therein to the head gates the river water that could be taken out at a higher point. Piles 8 inches by 8 inches by 16 feet were driven at 16-foot intervals on the line determined for the levee, and an embankment of brush and sand was formed behind the piling and connected to it. The flume was placed 50 feet from the face of the levee. It was constructed of cedar framing and sheeting, and was gradually submerged below the surface of the ground as it extended up the river. About 1,000 feet of these works were built during the year, extending upstream from the old head gates.

No official measurement of the water of the Gage canal was made during the year 1890, measurements having been deemed unnecessary because there was not a scarcity of water. Well No. 55 (the Camp well) was excavated during the year, but was not then used as a part

of the canal water supply. Its flow was estimated to be 50 miners' inches.

During the year 1891 pipe lines were placed on Maude, Horace, Washington, Gratton, Irving, Jackson, John, McAllister, and Stuart streets, and laterals from them were run to the lands of Arlington Heights, amounting in the aggregate to more than 1,000 acres. Masonry foundations were built for all of the flumes from No. 9 to No. 13, inclusive, and bulkheads were constructed at the canal for all of the entering pipe lines. Arrangements were made to cement the canal from the head gates to flume No. 6 wherever it had not already been cemented. During the latter part of the year contract therefor was made with Gray Brothers, of San Francisco, and work was begun in December between flumes Nos. 1 and 2. The work consisted of a thorough reconstruction of the canal by a realignment and regrading of all parts, resulting in a more perfect cross section. Plaster three-fourths of an inch thick, composed of one part Portland cement and four parts clean, sharp sand, was applied to all parts of the canal in natural banks; to all parts in made banks and side-hill work the outer slopes were lined with 6-inch masonry and then were plastered with cement. The ends of all flumes were incased in masonry abutments and retaining walls, freeing them from contact with the earth. During that year (1891) about 1,000 acres of land were planted on Arlington Heights. In 1889 an employee of the company was stationed at flume No. 3, whose duty it was to keep in repair the section of the canal along the bluff and to make a daily record of the quantity of water flowing in the canal at flume No. 3.

During the winter of 1890–91 floods carried away a portion of the levee and the casing of the channel behind it. This was owing to obstructions in the channel above the works, causing a diversion of the river which forced it to approach the levee at almost right angles, resulting in the cutting of a passage which exposed the channel behind to the destructive action of the water. During that season wells Nos. 1 to 6 and Nos. 13 to 27, inclusive, were excavated, making in the aggregate 21 additional wells.

The cementing of the canal as far as flume No. 6, as previously determined, was completed during the spring of 1892. In that year pipe lines also were placed on Arlington avenue and on Ana, Mary, Madison, Evans, St. Lawrence, Jefferson, Irving, Monroe, Van Buren, Robert, and Harrison streets, and a large number of laterals were extended from the mains to the lands and connected with the irrigating flumes. Considerable additional land was planted during the year, but not so much as during the previous year. Arrangements were also made to continue the cementing of the canal from the point where it had been completed in the spring to the upper end of flume No. 10, south of Terquisquite Arroyo. Contracts for this work were entered into with Gray Brothers. The work was begun during the month of December and continued during the remainder of the winter.

In this same year (1892) James Sheddan was made zanjero of the canal above flume No. 3, including head gates, artesian wells, and river, and the work of levee construction was carried on with vigor. The part of the levee between the head gates and well No. 39 was completed during the year and was tested by the floods of the following winter, with fairly satisfactory results. Wells Nos. 39 to 44, inclusive, were excavated, making 6 additional wells added to the system that year.

On November 11, 1892, careful measurements were begun of the total water supply of the Gage canal system developed up to that date, and were continued several days, for the purpose of determining many factors in connection with the water sources. The chief results are summarized in the following table:

Artesian wells of Gage canal system, 1892.

No. of well.	Distance apart.	Depth.	Diameter.	Temperature of water.	Pressure.	Capacity.
	Feet.	*Feet.*	*Inches.*	*Degrees.*	*Feet.*	*Miners' inches.*
1	0	656	10	75	25	5.00
2	1,216	534	10	74	70	32.50
3	296	382	10	74	76	29.00
4	525	482	10	74	74	41.20
5	561	320	10	73	23	3.50
6	265	784	10	74	80	45.00
7	4,620	196	10	70	11	13.70
8	353	190	10	70	11	21.00
9	204	142	10	70	11	3.50
10	320	148	10	68	12	3.20
11	714	141	7	67	28	24.50
12	80	181	7	68	29	21.60
13	765	426	10	70	16	86.50
14	530	472	10	70	17	101.50
15	1,680	518	10	64	17	62.50
16	190	388	10	66	50	50.00
17	175	380	10	65	50	32.00
18	480	386	10	62	50	27.00
19	330	196	10	62	17	43.50
20	270	124	10	62	12	9.50
21	260	116	10	62	13	24.70
22	270	134	10	62	17	50.50
23	265	168	10	62	11	36.00
24	265	166	10	62	14	26.00
25	320	152	10	62	14	19.70
26	280	123	10	62	13	21.00
27	320	125	10	62	14	9.00
28	280	144	10	62	15	38.00
29	310	140	10	62	16	28.30
30	790	138	10	62	13	11.20
31	430	108	10	64	15	3.70
32	35	130	10	64	16	16.20
33	315	146	10	63	18	41.00
34	550	116	10	63	16	48.00
35	130	134	10	63	15	30.50
36	120	116	10	64	16	16.00
37	680	147	10	66	16	42.00
38	90	122	10	66	16	28.75
39	276	115	10	66	17	10.50
40	1,090	169	10	66	17	77.15
41	474	193	10	66	14	63.50
42	510	192	10	66	17	85.75
43	510	390	10	66	18	109.75
44	500	224	10	64	20	92.75
45	1,580	123	7	62	25	76.50
46	15	133	7	62	25	6.70
47	15	133	7	62	25	24.40
48	40	139	7	62	25	29.33
49	50	211	7	62	23	28.40
50	40	100	7	62	25	15.00
55	1,590	300	10	64	22	80.00
Total						1,793.45

It will be understood that the gagings are minimum measurements taken at the end of the irrigation season and while all of the wells were running open and part of them had been running open during the season. The pressure (in feet) of each well was taken while it was closed. The average flow for each well is 35.15 miners' inches; the total flow is 1,793.45 miners' inches, or 23,243,112 gallons daily.

The work of completing the cementing of the canal was prosecuted during the first three months of the year 1893 and was completed in time for irrigation. Pipe lines were placed on Monroe and Gibson streets and laterals were laid to about 800 additional acres of land. An improved hydrant and hydrant box were adopted—the latter being formed of cement—and attached to all of the irrigation laterals and flumes that were put in during that year; in cases where new boxes were needed elsewhere the improved boxes were placed on the old forms. About 800 additional acres were planted to oranges and lemons during 1893, and arrangements were made during the latter months of that year for the cementing of certain portions of the canal south of flume No. 10 in the same manner as work already done, but the company decided this time to do the work under its own supervision. The work of excavating the channel behind the levee was also carried on, and was completed as far as the finished portion of the levee. The levee was extended up the river about a half mile, or a considerable distance above the adjacent wells. No additional wells were excavated during the year.

In 1894 the work of cementing the canal south of flume No. 10 was proceeded with during the spring months, and about 1,200 feet immediately south of the flume and Arlington avenue were cemented; water service was added to about 200 acres of land, which were planted the same year to orange and lemon trees. The trenching on the south side of the river was continued during the spring of that year, and at a distance of 5,650 feet (1.07 miles) upstream connection was made with the river. The river water owned by the Riverside Trust Company was diverted into this new channel, and the whole supply on the south side of the river, including the wells, was carried through the channel to the head gates. A channel on the north side of the river from the head gates upstream was also commenced and a large portion of it was finished that year.

During the years 1895 to 1898, inclusive, the levee in the river bottom was extended and added to from time to time, until now it extends on both sides of the river a distance of about 2 miles upstream from the original headworks.

WATER SUPPLY.

The water supply of the Gage canal system is, as already stated, largely from artesian wells. During years of drought the supply is wholly from wells. The number of wells has been increased from year to year, as the demand for water grew and as the old wells

became silted up. It is also probable that the extreme drought from 1892 to 1900, coupled with the general increased demand upon this artesian basin, has reduced the flow of the wells. Their maintenance is remarkable, and is one of the numerous evidences of the vast extent of the supply.

The number of wells in the Gage system and their output are as follows:

	Miners' inches.
1887, 14 wells, approximately	600
Fall of 1888, 26 wells	1,135
Spring of 1889, 27 wells	1,091
October, 1892, 55 wells	1,793
June, 1899, 68 wells	1,440

In June, 1899, 55 of the 68 wells were flowing and 13 of them were not flowing. The maximum output is stated by the company to have been 1,440 miners' inches. The company has a right to 289.5 miners' inches at its headworks on Santa Ana River, but during recent dry years this has been of little value. On June 20, 1899, there were at that point 12 miners' inches, and on February 21, 1900, 20 miners' inches. The Parish ditch, which is said to have a normal flow of 120 miners' inches, is now dry.

The sources of water supply to this canal, including the right to develop additional water over an area of 488 acres forming part of a block of water-bearing land, are 2,831 acres, all of which are owned by the company. In 1893 the supply, including river water, was estimated as follows:

	Miners' inches.
Santa Ana River	289.50
Artesian wells, 55 in number, measured at their minimum flow (October 10, 1892)	1,793.45
Parish ditch	20.00
Total	2,102.95

The artesian wells are distributed over a considerable area, but generally extend (for a distance of 15,800 feet) along the canal bank and the river bottom, as shown on the map, Pl. I.

All of the wells were driven by means of a sand pump working inside of a thick, double iron casing or lining, the lining being forced down by means of hydraulic jacks as the pump continued to excavate. The lining is of No. 10 or No. 12 gage iron, in two thicknesses, so that it can be built up and made continuous by inserting inside and outside lengths alternately, each length being 2 feet long and breaking joint in the center. The casing fits so exactly that in a short time the lining becomes, by oxidation, water tight, at least sufficiently so for the purpose.

As already stated, in the spring of 1889 Prof. E. W. Hilgard, of the University of California, made an examination of the artesian water supply of the Gage canal system for the Home Life Insurance Com-

pany, of San Francisco. He was given exceptional opportunities for an exhaustive study, and his report, which is of general interest, is freely quoted from below. He states that the water supply at that time (April, 1889) was as follows:

	Miners' inches.
Supply from 27 wells	1,091
Parish ditch	157
Water right in Santa Ana River	289
South Side ditch (estimated)	75
Total	1,612

On June 30, 1898, there was flowing in the Gage canal at Palm avenue a total of 1,313 miners' inches; on June 20, 1899, 1,273 miners' inches; and on February 21, 1900, 1,129 miners' inches. A reference to the table of rainfall on page 17 will show that the last eight years have been years of unusual drought, and that the season of 1888–89 was in a group of wet years. These wells have, therefore, maintained their supply in the face of the drought and in spite of the fact that the underground gravel reservoir has been heavily drawn upon by other sources. (See general discussion of water supply, page 36.)

The following extracts are made from Professor Hilgard's report:

The bulk of the supply of the Gage Canal is at present from artesian wells, of which there are 42 on the Victoria tract. On the "water tract" proper there are 27 now flowing or ready to flow. These wells are located in four groups, designated by the letters of the alphabet, from A to D. The lettering for these groups of wells is that adopted in the State engineer's report on irrigation in southern California. The difference in the number of wells forming the several groups and the increased supply of water are due to the boring of additional wells since the State engineer's observations were made.

The wells of each group are separately numbered, in general upstream and counting from south to north. The following data show the number of each group, distances from each other and from the head gate of canal, and the measured flow of each well in miners' inches of 4-inch pressure, the measurement usually adopted in southern California.

GROUP A.

Six wells in line along the canal, the nearest being 2,400 feet from the head gate, and the total distance from No. 1 to No. 6, 1,665 feet.

Measurements of wells in group A.

Number of well.	Distance from well next above.	Diameter of pipe.	Discharge.	Number of well.	Distance from well next above.	Diameter of pipe.	Discharge.
	Feet.	*Inches.*	*Miners' inches.*		*Feet.*	*Inches.*	*Miners' inches.*
1	249	10	36	5	67	7	57
2	304	10	68	6		7	46
3	323	10	35				
4	722	10	18	Total			260

GROUP B.

Six wells occupying an area of somewhat less than an acre (3,900 square feet), distance 1,200 feet from the head gate in a northwest direction; distance from (center of) group C, 3,276 feet.

Measurements of wells in group B.

Number of well.	Distance from well next above.	Diameter of pipe.	Discharge.	Number of well.	Distance from well next above.	Diameter of pipe.	Discharge.
	Feet.	*Inches.*	*Miners' inches.*		*Feet.*	*Inches.*	*Miners' inches.*
1	15	7	28	5	40	7	63
2	15	7	17	6		7	20
3	40	7	36				
4	50	7	39	Total			225

GROUP C.

Consisting of four weak wells, all with 7-inch pipe, among the first bored, and left as they are at an average depth of about 110 feet on account of difficulties encountered in the cobble layer at bottom, for overcoming which suitable tools were not then at hand. The wells are between 10 and 18 feet apart only, and yield from 7 to 12 inches of water each; total, 35 inches. One good 10-inch well would probably give better results than the four small ones.

This group is distant 4,550 feet northeast from group B and 2,100 feet from the center of group D. Area actually occupied, 360 square feet.

GROUP D.

This group consists of 11 wells (all with 10-inch pipe), ranging in depth from 110 to 160 feet. Nine are located on the south side of and mostly quite near to the river bed; two are near the north bank, one being in the present bed. The distance between the centers of groups A and B is about 5,800 feet; between D and B, 4,400 feet. The elevation above group B is about 18 feet; above group A, 31 feet. Area actually occupied by the group, 17 acres.

Measurements of wells in group D.

Number of well.	Distance from well next above.	Discharge.	Number of well.	Distance from well next above.	Discharge.
	Feet.	*Miners' inches.*		*Feet.*	*Miners' inches.*
1	80	51	8	440	22
2	687	51	9		37
3	117	43	10	300	56
4	139	55	11		74
5	566	82			
6	315	65	Total		571
7	42	35			

All the measurements recorded above correspond to the condition of the wells about thirty-six hours after all had been uncapped and had been running their full streams.

This point is of some importance, because measurements made immediately or soon after uncapping a well that has been closed for some time show at first a considerably larger dscharge, evidently due to accumulated pressure, or what might be called a "local head," requiring some time to run down to the nominal discharge.

DEGREE OF INTERDEPENDENCE OF WELLS.

The extent to which the discharge of any well or group of wells is influenced by that of others situated at a greater or less distance is a question of great practical interest, since upon the answer depends the aggregate amount of water to be expected from further developments on the "water tract" by boring additional wells. I have tested the point in a variety of ways, the more important being the following:

(1) Well No. 6 in group B has for some time past remained capped, with an inch pipe carrying the water to a dwelling house some 300 yards away, the water reaching the level of 26 feet above the casing when all the other wells of the group are capped. It was found when all the other wells are uncapped the water level at the house falls about 3 feet 7 inches. As stated above, the total flow of the wells of this group is 225 inches; that of No. 6, 20 inches. It is distant only 40 feet from well No. 5, having a flow of 63 inches, and all the rest of the group lie within 130 feet. Yet the measurement shows that the opening or shutting down of a flow of 205 inches, or more than ten times the amount of the flow of No. 6, influences its head to the extent of not quite 14 per cent, or three-quarters of 1 per cent of the total discharge of the group.

(2) Well No. 2 of group D had been steadily running for upward of a year, all the rest of the group, as well as those of groups B and C, being closed. It was then discharging about 61 inches. After nine other wells (Nos. 3 to 11, inclusive) had been uncapped, No. 2 was found to have decreased to 57 inches in the course of about three hours. On opening No. 1, within 80 feet of No. 2, its flow fell off to 55 inches, and forty-eight hours afterwards it had reached its minimum flow of 48.4 inches, which, however, five hours after was found to have risen again to 51 inches, the figure adopted in the table above. Such fluctuations of a few inches appeared of measurements made at different times of the day, in almost all cases of strong flow, possibly as the result of barometric variations or other diurnal causes.

It will be seen that in the case of this well the letting loose of 520 inches of water within an area of 17 acres immediately adjacent caused a decrease of the flow it had when running by itself of only 10 inches, being about one-sixth, or, say, 17 per cent, of its maximum flow when all the rest were closed, or 1¾ per cent of the total discharge of the group. It will be noted that this is very nearly the same ratio as in the case of well No. 6 in group B reported above.

(3) After the wells had all reached a state of sensibly normal discharge, groups C and D, with their aggregate discharge of 606 inches, were shut down about 5 p. m., in order to observe the effect on other groups.

Group B was measured at 10 p. m., and was found to be discharging 211 inches. Six hours before, when all the other wells were still open, the flow was 205 inches, thus showing an increase of 6 inches, possibly caused by the shutting down of an aggregate of 606 inches at the average distance of about a mile. This is a very slight effect at best, being less than 1 per cent of the total amount shut off, or three-fourths of 1 per cent of the total discharge concerned, and less than 3 per cent of the discharge of the five open wells of the group. But the fact that on the morning of the same day these wells stand credited with a discharge of 215 inches renders it even doubtful that the shutting down of groups C and D caused the observed increase, and that it was not merely due to diurnal variations referred to above and known to exist. Unfortunately my time did not permit of the continuation of the observations so as to settle this point definitely.

(4) On the following day, eighteen hours after the shutting down of all the other groups, representing an aggregate of 831 inches, at an average distance of about 5,000 feet, group A was remeasured. It was found that the discharge of well No. 1 had decreased from 36 to 29 inches, evidently in consequence of being loaded down with a quantity of gravel that had slid in from above, the pipe having

sunk below the ground level. In the rest of the group (Nos. 2 to 6) there had been an increase over the discharge observed in the afternoon of the previous day from 224 to 233 inches, a difference of 9 inches in the total discharge of the group, or 4 per cent of its volume, but only a little over a third of 1 per cent of the total discharge concerned.

(5) A striking proof of the relative independence of these wells of one another when situated at reasonable distances apart is found in the "local head," or accumulation of pressure that takes place so soon as an individual well is shut down. When measured immediately after uncapping, a well that has remained closed for some time is found to discharge from 15 to 17 per cent (in the large wells) more than its normal flow, to which it settles down after a lapse of from twenty to thirty hours. This accumulation and slow running down proves conclusively that we have here to do, not with an ordinary hydrostatic column, but with a mass of water so subdivided by the closely packed materials intervening between the vents made by the auger and in the interspaces in which the water is stored that a rapid transmission of pressure is not possible, *and that the laws of hydraulics and friction, rather than those of hydrostatics, must be held to govern the discharge.* Moreover, it proves that hundreds of inches of water discharge bear but a very small ratio to the total supply that lies behind these artesian fountains.

The nature of these materials as disclosed by the auger or sand pump is found to be gravel (ranging from pea size up to cobbles of greater diameter than even the 10-inch pipes), tightly packed with sand of various degrees of fineness. Cobbles nearly filling the pipes—over 7 pounds in weight—have in several instances been ejected by the water pressure from some of these wells. The character of these cobbles can not be mistaken; they represent the same rocks that have been and are now being brought down from the Santa Ana and Mill Creek canyons at the head of the valley, where a wilderness of the same materials (ranging all the way from fine sand up to bowlders of 5 feet in diameter) cover many square miles of surface and are shown in every break of the country. There, as well as in the borings, occasional sheets or strata of clay or other impervious materials alternate with the gravel and cobble deposits, and with the penetration of each such clay layer additional water pressure is obtained in the wells. The sources of Warm Creek, the Parish Ditch, and of such outflows as "Hunt's Spring" doubtless indicate the termination or the perforation from some cause of such impervious water-shedding strata not far from the surface.

On page 23 is an analysis of water from wells in groups A and D of this system.

In October, 1892, the owners of the Gage canal system conducted a series of experiments on 55 artesian wells and obtained results at variance with the previous experiment.[a] The numbers indicated in the first column of the table correspond with numbers on Pl. I and show the locations of the wells. The third column of the table gives the distance to the nearest well, the fourth column the static pressure, in feet, when each well is closed. The fifth column (final measurement, reduced to miners' inches) gives the amount of water that each well was flowing at the end of the experiment, when all of the wells following it in the table were open. For instance, when well No. 115, which corresponds to well No. 1 of the Gage Canal Company's numbering, was open and all of the other wells were closed its discharge was in both instances 5 miners' inches. When well No. 116 was open and

[a] This is probably due to the more complete development of the entire supply by the Gage Canal Company and others.

all of the other wells were closed its discharge was 46 miners' inches; but when all other wells following in the list were open its discharge was 32.5 miners' inches. The seventh column gives the percentage of decrease in the flow of this particular well under the foregoing conditions. The eighth column gives the cumulative number of the original measurement, in miners' inches. In other words, it is the sum of the flow of any well and of all of the wells preceding it in the table, on the basis of one well alone being open. For example, well No. 115 being open and all of the other wells closed, it flows 5 miners' inches. Well No. 116 being open and all of the others closed it flows 46 miners' inches. Then the cumulative number of the original measurement, in miners' inches, corresponding to well No. 116 would be the sum of these two volumes, or 51 miners' inches. The ninth column gives the cumulative number of final measurements, in miners' inches, which is the sum of the discharge, on the basis of the other wells all flowing; as, for instance, in the case of well No. 116, when the other wells are open it would discharge 32.5 miners' inches, which added to the discharge of well No. 115 gives a total for the two wells of 37.5 miners' inches. The tenth column gives the percentage of decrease at each point of comparison between the seventh and eighth columns. The last column of the table gives the temperature of the water.

Fifty-five wells are considered in these experiments, and while the total volume of water obtained increased as more wells were opened, the aggregate flow is not so great, by 52 per cent, as the sum of the flow of all of the individual wells.

From the foregoing it will be seen that in this particular instance a gain was made by boring as many as 55 wells, but it is also indicated that the number of wells could not be increased indefinitely at a financial profit.

Table showing effect of opening and closing neighboring artesian wells of the Gage canal system.[a]

Quadrangle.	New number of well.[b]	Old number of well.	Distance between wells.	Pressure.	Final measurement.	Original measurement.	Difference between original and final measurements.	Cumulative quantity of original measurements.	Cumulative quantity of final measurements.	Decrease in volume.	Temperature of water.
			Feet.	*Feet.*	*Miners' inches.*	*Miners' inches.*	*P. cent.*	*Miners' inches.*	*Miners' inches.*	*P. cent.*	*Degrees.*
San Bernardino	115	1	0	24.75	5.00	5.00	0	5.00	5.00	0	75.0
Do	116	2	1,216	70.40	32.50	46.00	30	51.00	37.50	27	74.0
Do	117	3	296	75.90	29.00	37.00	22	88.00	66.50	24¼	74.0
Do	118	4	525	73.60	41.25	48.75	15	136.75	107.75	21¼	74.0
Do	119	5	551	23.00	3.50	3.50	0	140.25	111.25	21	73.0
Do	120	6	265	80.50	45.00	51.75	13	192.00	156.25	19	74.0
Do	121	7	4,620	11.00	13.75	27.50	50	219.50	170.00	23	70.0
Do	122	8	353	11.00	21.00	46.00	55	265.50	191.00	28	70.0
Do	123	9	204	12.50	3.50	9.75	64	275.25	194.50	29	70.0
Do	124	10	321	12.50	3.25	6.00	46	281.25	197.75	30	68.5
Do	125	11	714	28.00	24.50	58.00	58	339.25	222.25	35	67.0

[a] Courtesy of W. Irving, engineer of Gage canal system.
[b] These are the numbers shown on Pl. I.

Table showing effect of opening and closing neighboring artesian wells of the Gage canal system—Continued.

Quadrangle.	Old number of well.	New number of well.	Distance between wells.	Pressure.	Final measurement.	Original measurement.	Difference between original and final measurements.	Cumulative quantity of original measurements.	Cumulative quantity of final measurements.	Decrease in volume.	Temperature of water.
			Feet.	*Lbs.*	*Miners' inches.*	*Miners' inches.*	*P. cent.*	*Miners' inches.*	*Miners' inches.*	*P. cent.*	*Degrees.*
San Bernardino	126	12	80	29.00	21.62	49.75	57	389.00	243.37	37½	8.0
Do	127	13	765	16.10	86.50	150.00	43	539.00	330.37	39	760.0
Do	128	14	530	16.95	101.50	162.00	37	701.00	431.87	39	70.0
Do	129	15	1,680	[a] 17.00	62.50	80.50	23	781.50	494.37	37	64.5
Do	130	16	180	50.60	50.00	60.50	18	842.00	544.37	36	66.0
Do	131	17	175	50.00	32.00	37.50	15	879.50	576.27	35	65.0
Do	132	18	480	[a] 50.00	27.00	71.50	63	951.00	603.37	37	62.0
Do	133	19	330	16.95	43.50	143.00	70	1,094.00	646.87	43	62.0
Do	134	20	270	12.00	9.50	60.00	84	1,154.00	656.37	44	62.0
Do	135	21	260	13.20	24.75	104.00	77	1,258.00	681.12	46	62.0
Do	136	22	270	16.90	50.50	146.00	66	1,404.00	731.62	48	62.0
Redlands	391	23	265	10.90	36.00	132.50	73	1,536.00	767.62	51	62.0
Do	392	24	265	13.80	26.00	68.75	62	1,605.25	793.62	51	62.0
Do	393	25	320	13.80	19.75	68.75	71	1,674.00	813.37	52	62.0
Do	394	26	280	12.60	21.00	75.00	72	1,749.00	834.37	54	62.0
Do	395	27	320	13.80	9.00	34.00	73	1,783.00	843.37	54	62.0
Do	396	28	280	15.00	38.00	88.50	58	1,871.50	881.37	53	62.0
Do	397	29	310	16.10	28.85	47.00	39	1,918.50	910.22	53	62.0
Do	398	30	790	12.60	11.25	30.00	63	1,948.50	921.47	53	62.0
Do	399	31	430	14.90	3.75	9.50	60	1,958.00	925.22	53	64.0
Do	400	32	35	16.10	16.25	28.50	48	1,986.50	941.47	53	64.0
Do	401	33	315	18.40	41.00	90.00	55	2,076.50	982.47	53	63.0
Do	402	34	550	([b])	48.00	98.30	52	2,174.80	1,030.47	53	63.0
Do	403	35	130	15.50	30.50	65.75	54	2,240.55	1,060.97	53	63.0
Do	404	36	120	16.10	16.00	29.50	46	2,270.05	1,076.97	53	64.0
Do	405	37	680	16.00	42.00	92.00	55	2,362.05	1,118.97	54	66.0
Do	406	38	90	16.00	28.75	48.75	41	2,410.80	1,147.72	53	66.0
Do	407	39	279	16.90	10.50	24.75	58	2,435.55	1,158.22	53	66.0
Do	408	40	1,090	16.90	77.15	166.00	53	2,601.55	1,235.37	53	66.0
San Bernardino	155	41	474	13.80	69.50	168.00	58	2,769.55	1,304.87	53	66.0
Do	156	42	510	16.90	85.75	169.00	50	2,938.55	1,390.62	53	66.0
Do	157	43	510	18.00	109.75	137.00	20	3,075.55	1,500.37	52	66.0
Do	158	44	307	20.00	92.75	146.00	37	3,221.55	1,593.12	51	64.0
Do	159	45	1,580	25.00	16.50	46.25	60	3,267.80	1,609.62	51	62.0
Do	160	46	15	25.00	6.70	16.75	60	3,284.55	1,616.32	51	62.0
Do	161	47	15	25.00	26.40	66.00	60	3,350.55	1,640.72	52	62.0
Do	162	48	40	25.00	29.33	50.84	60	3,401.39	1,670.05	51	62.0
Do	163	49	50	23.20	26.40	76.00	60	3,477.39	1,698.45	52	62.0
Do	164	50	40	25.00	15.00	[a] 20.00	25	3,497.39	1,713.45	51	62.0
Redlands	409	51	4,440	19.00	00.00	7.00	100	3,504.39	1,713.45	52	64.0
Do	410	52	20	19.00	00.00	7.10	100	3,511.49	1,713.45	52	64.0
Do	411	53	25	19.00	00.00	7.00	100	3,518.49	1,713.45	52	64.0
Do	412	54	25	19.00	00.00	10.50	100	3,528.99	1,713.45	52	65.0
San Bernardino	169	55	5,070	22.00	80.00	150.00	56	3,678.99	1,793.45	52	64.0

[a] Estimated. [b] Left open.

DIVERTING DAM.

The river water is diverted into the canal by means of temporary brush and sand dams, which are renewed each year; but owing to the natural conditions in the river bottom the renewal is a work of small expense compared with the cost of permanent works sufficient to withstand the action of floods, which sometimes exceed 2,000 cubic feet per second over a bed composed of sand and gravel several hundred feet in depth. In a few hours after the river reaches its maximum discharge it recedes to its normal flow, when the whole of it can if necessary be diverted into the canal by throwing up an embankment of sand a few inches above the water surface.

HEAD GATES.

The head gates are strongly constructed of heavy timbers and have three sets of regulating gates, opened by means of ratchets and pin-

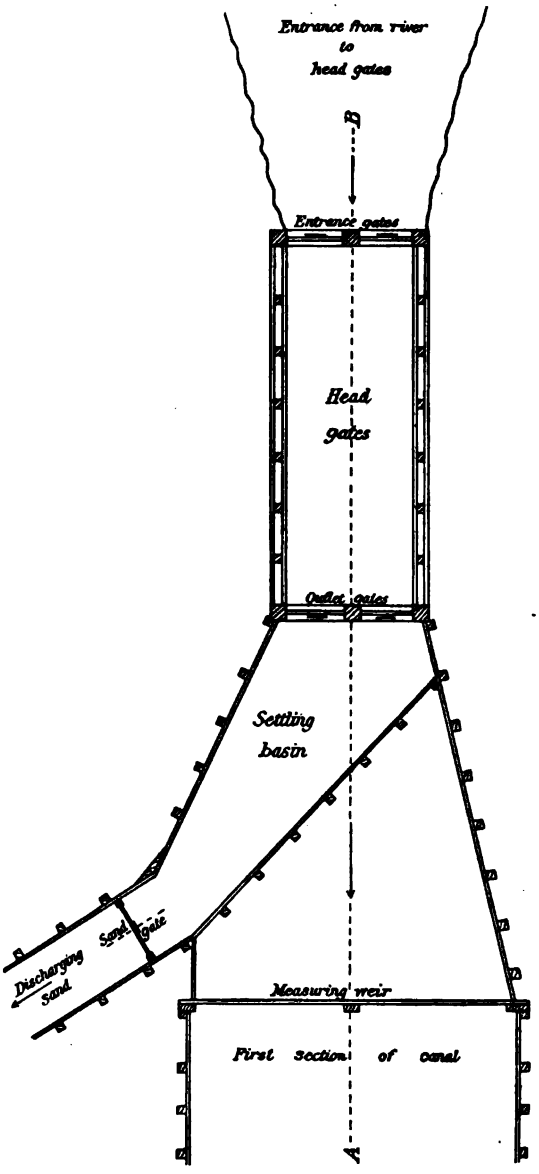


FIG. 3.—Plan showing arrangement of head gates of Gage canal.

ions, one set being sand gates for the discharge of the surplus water and the moving sand. (See fig. 3.)

The water discharges out of the head gates into a settling basin, from which it is measured over a weir into the canal. Figs. 3, 4, and 5 show the head gates and the measuring weir. In connection with the weir there is an automatic register by means of which a record is

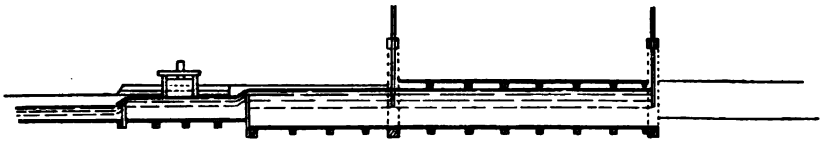


FIG. 4.—Section of headworks of Gage canal, on line A-B of fig. 3.

made of the amount of water flowing into the canal at all times during the irrigation season.

In addition to the automatic register there is an automatic electric alarm by means of which high and low water during the night are

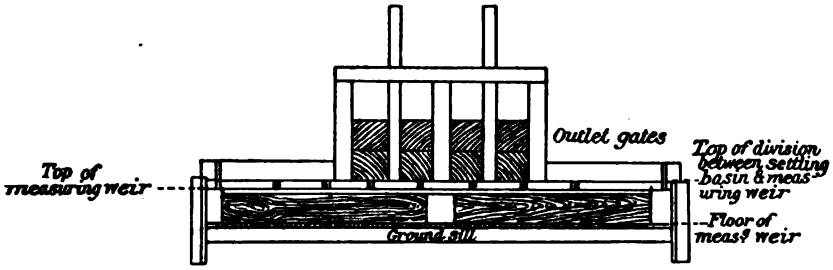


FIG. 5.—End elevation of measuring weir on Gage canal, showing end elevation of outlet gates beyond.

made known to the attendant. The cylinder on which the changes are traced receives its motion from a clock movement and makes one revolution in seven days.

The weir over which the water is measured is 23 feet long. The canal at the weir is 24 feet wide and serves as a settling basin for the moving sand, which at times causes trouble. For a distance of a few hundred feet from the head gates the banks of the canal are lined with wooden sheeting, gradually narrowing from a width on the bottom of 24 feet at the head gates to 10 feet where the cemented portion begins. From that point for a distance of 2,950 feet the canal gradually rises from the river bottom proper to the plain of the first mesa lands and to flume No. 1, over a small local arroyo; thence, at a distance of 8,500 feet, through the same mesa lands to flume No. 2, over a small creek; thence, at a distance of 15,650 feet, through the mesa lands to tunnel No. 1 and the base of a range of foothills; thence, at a distance of 21,050 feet, by a series of tunnels and along the face of

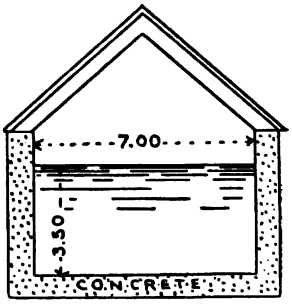


FIG. 6.—Section of tunnel No. 1, in earth, of Gage canal system.

the foothills to flume No. 3. A section of tunnel No. 1 is shown in fig. 6. The canal continues along the bluffs in a series of tunnels, fills, and flumes Nos. 4, 5, and 6 until it passes onto the upper plains at a distance of 27,200 feet. From that point it follows the natural contour of the land, crosses an arroyo by means of flume No. 8 (flume No. 7 being now a fill), and at a distance of 45,600 feet from its head it passes through the projecting point of a foothill by means of a tunnel, and then continues along the natural contour to flume No. 9, over Terquisquite Arroyo, at a distance of 62,800 feet, or 11.9 miles; then, by means of flumes, fills, and cuts, it crosses the arroyo between the foothills and follows the natural contour of the land to the end, the total length being 106,444 feet, or 20.16 miles.

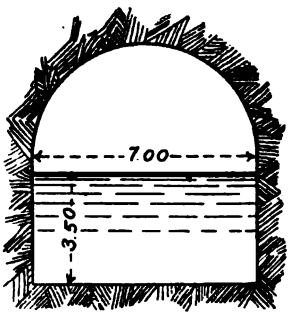


FIG. 7.—Section of tunnel in rock on Gage canal system.

CEMENT LINING.

Generally the slope of the sides of the canal is 4 perpendicular to 3 horizontal.

From the head gates to flume No. 10 the canal is lined with masonry, as are also all tunnels and fills, to a depth of 5 inches, and then is plastered with cement mortar; the remaining portions are lined with cement plaster to a thickness of three-fourths of an inch. Of the whole length of the canal (20.16 miles) 14.5 miles

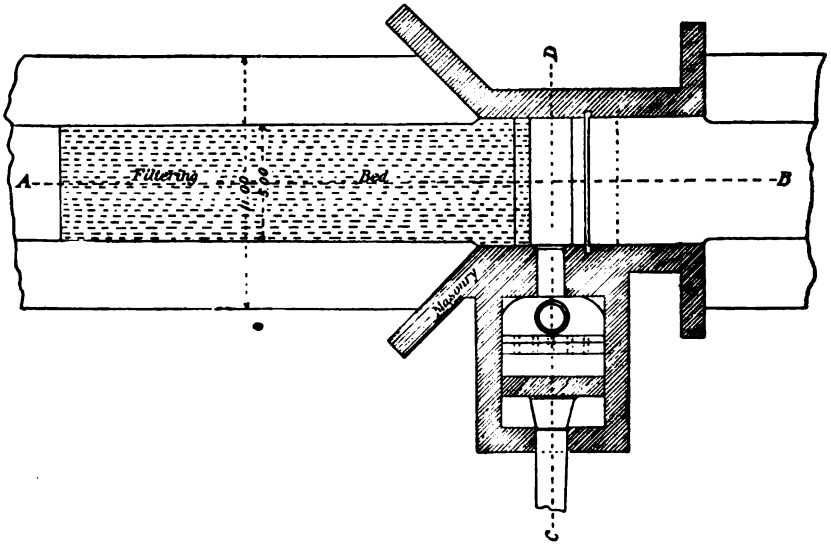


FIG. 8.—Plan of bulkhead and orchard lateral connection on Gage canal system.

are lined with cement. Most of this work was done during the winter months from 1891 to 1894, and at an average cost of $1.50 per foot, or a total cost of $114,135. While it can be said that this cement lining has not stood well, it can also be said that it has stood better than was

expected under the conditions. When in increasing the capacity of a channel it is a question of spending $75,000 in one case and $200,000 in the other case, and saving an important percentage of irrigation water, it may be excusable to take some risk. Large surfaces of cement coating three-fourths inch thick can not be expected to stand much strain under the action of storm waters, and it is to this action that nearly all ruptures of the coating are due. Had there been intervals of time during recent dry years to close the canal for repairs

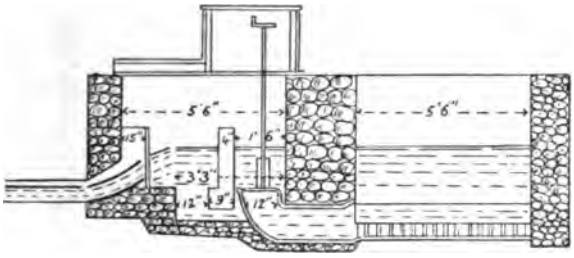


FIG. 9.—Cross section of bulkhead and orchard lateral on Gage canal system, on line C-D of fig. 8.

its condition would be much better. No repairs have been made during the last four years, and the estimated cost of a thorough renovation is less than $1,000, which spread over four years is only a fraction of 1 per cent of the original cost.

The cross section of the canal varies with the distance from the head gates. The bottom width below the head gates is 10 feet, as already stated, which is gradually reduced to 6 feet at flume No. 10; from that point to near the end the width is 5 feet. The canal has a uniform depth of 4 feet throughout its entire length.

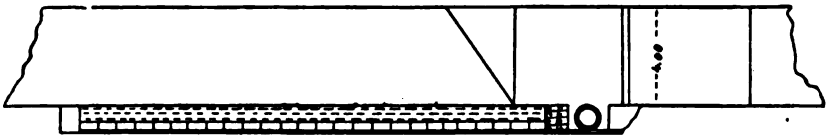


FIG. 10.—Longitudinal section of bulkhead and orchard lateral on Gage canal system, on line A-B of fig. 8.

The total length of tunnels is 5,250 feet. Where they pass through earth formation the bottom and sides are lined with concrete masonry and the roofs are heavily timbered.

The total length of flumes is 4,000 feet. All are strongly framed, rest on masonry foundations, and have retaining walls and foundations at each end where they connect with the other parts of the canal.

CAPACITY.

The capacity of the canal at various localities, as stated by the engineer of the company in 1899, is as follows:

	Miners' inches.
Canal 1.5 miles from headworks	9,646
Tunnel 3 miles from headworks	4,630
Flume 4 miles from headworks	4,270

	Miners' inches.
Weir 5.7 miles from headworks	2,215
Flume 7.5 miles from headworks	4,060
Flume 11.9 miles from headworks	3,166
Canal 12.5 miles from headworks	4,375
Flume 14.75 miles from headworks	3,436
Flume 18.5 miles from headworks	3,350
Pipe line (12-inch) to San Jacinto Land Company from south end of canal	346

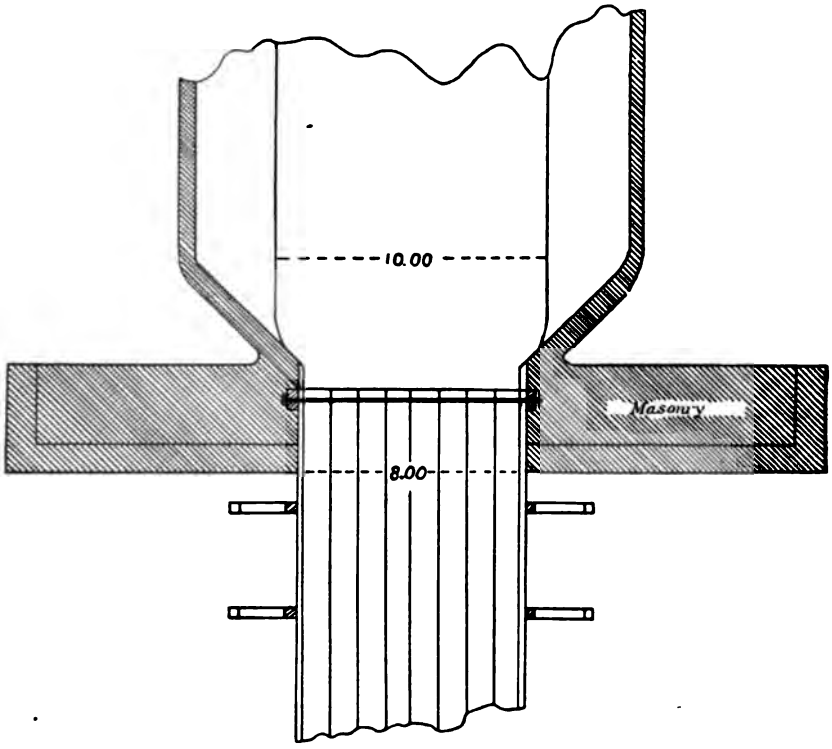


FIG. 11.—Plan showing junction of canal and flume on Gage canal system.

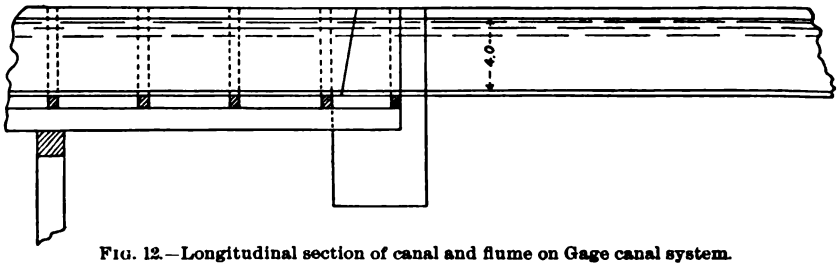


FIG. 12.—Longitudinal section of canal and flume on Gage canal system.

In 1899 the upper section of the canal was carrying 1,440 miners' inches; at the lower end of the middle section there were 742 miners' inches, while at the extreme southerly end of the canal the San Jacinto Land Company was taking out through its pipe line, for the supply to

530 acres under cultivation, all of the water remaining in the canal, viz, about 106 miners' inches, or 1 miners' inch to each 5 acres. This

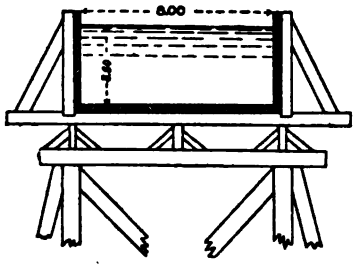


FIG. 13.—Section of flume and trestle on Gage canal system.

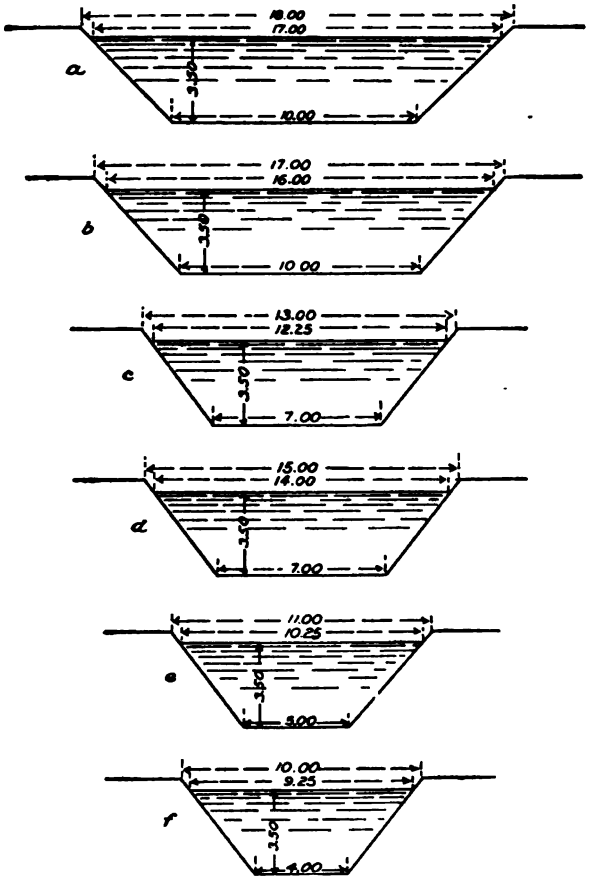


FIG. 14.—Cross sections of Gage canal: *a*, 336 feet from head; *b*, 1.62 miles from head; *c*, 3 miles from head; *d*, 8.55 miles from head; *e*, 18.69 miles from head; *f*, at terminus.

duty of 1 inch to 5 acres was then and still is in force on all cultivated lands under the Gage canal. The canal gave nearly the full water supply to its underlying lands during the drought of 1897–1900.

The following table gives the value of the hydraulic elements in the various sections of the canal.

Table showing value of hydraulic elements in sections of Gage canal.

	A.	B.	C.	D.	E.	F.
Distance from head, in miles	0.064	1.62	3	8.55	18.69	.....
Slope	.000413	.00052	.000383	.000478	.0004	0.0004
Area of cross section, in feet	47.25	45.5	33.25	33.67	26.68	23.18
Perimeter of cross section, in square feet	19.80	19.1	15.60	15.75	13.75	12.75
Hydraulic mean radius	2.38	2.38	2.13	2.13	1.94	1.82
Coefficient of roughness	.014	.014	.014	.014	.014	.014
Coefficient	121	121	119	119	118	118
Discharge, in miners' inches	8,953	9,646	5,635	6,380	4,375	3,686

DIVERSIONS.

East Riverside.—About 30,000 feet from the head gates the first distributing pipe in the East Riverside district connects with the canal, and from that point to flume No. 9, over Terquisquite Arroyo, distributing pipes enter the canal at intervals of about one-fourth of a mile. Throughout this whole distance metal valves inserted in brickwork are provided at all distributing points. (See figs. 8, 9, and 10.) The distribution system is under command of an officer whose duty it is to subdivide the water to the several owners in accordance with their shares and with the by-laws adopted by themselves, through their representatives, for its management and distribution. Fig. 11 shows the junction of canal and flume generally used on the Gage canal system.

The amount of land served by the canal in the East Riverside district, extending from the first diversion described to flume No. 9, its southerly limit, is 3,620 acres, nearly all of which is now under cultivation.

Lands served by Gage canal in East Riverside district.

	Acres.
Growing oranges	3,000
Growing lemons	40
Growing deciduous fruits	40
Growing alfalfa	40
Total cultivated area	3,120
Uncultivated area	500
Total	3,620

Arlington Heights.—At a distance of 71,900 feet from the head gates, and about 1½ miles from flume No. 9, the lands of Arlington Heights are reached. These lands are subdivided, by streets, at intervals of one-fourth of a mile, each block of about 40 acres being bounded by streets and the block again subdivided into 10-acre lots.

The total acreage served by the canal at Arlington Heights is a little more than 4,890 acres, divided as follows:

Lands at Arlington Heights served by Gage canal.

	Acres.
Growing oranges	2,200
Growing lemons	520
Growing grape fruit	170
Total cultivated area	2,890
Uncultivated area	2,000
Total area subject to canal	4,890

Pipe lines.—The distribution of water is by means of steel pipes carried down each street transverse to the canal, with lateral connections to each 10-acre lot, the water being carried to the highest point and furnished with a hydrant and measuring weir. From the hydrants open flumes are laid along the highest boundaries of the lots, from which the water is served to the irrigating furrows between the trees. At the end of each pipe line where it enters the canal bulkhead is a regulating valve and a measuring weir. (See figs. 8, 9, and 10.)

The main pipe lines on the streets vary in diameter from 10 inches at the canal to 6 inches at the lowest point. The greatest pressure to which the pipes are subjected is equal to a head of 164 feet, or 70 pounds to the square inch. The pipes are formed of riveted steel plate, No. 14 to 18 gage, coated with an asphaltum preparation.

On the distribution system of Arlington Heights there are 287 hydrants, or an average of one hydrant to each 10 acres. The hydrants are manufactured by the Lacy Manufacturing Company, of Los Angeles, from a special design by Mr. William Irving, engineer of the Gage canal system. Hydrants are furnished to the irrigators at a cost of $10 in place. Over the hydrant is set a cement hydrant box, which is made by the Gage Canal Company and set in place at an expense to the irrigators of $10 each, which represents the actual cost. In the distribution system of Arlington Heights there are the following lengths of steel pipe:

4,800 feet of 12-inch, costing 66 cents per foot laid.
4,000 feet of 10-inch, costing 56 cents per foot laid.
36,500 feet of 8-inch, costing 47 cents per foot laid.
88,400 feet of 6-inch, costing 36 cents per foot laid.
147,200 feet of 4-inch, costing 26 cents per foot laid

This represents a total cost of $92,660 for the pipe in that system.

Detailed data pertaining to the distribution system of East Riverside under the Gage canal can not be obtained, but the cost, using the Arlington Heights factor of acreage, which will give results very close to the correct figures, would be $102,000. The method of distribution for East Riverside lands under the Gage canal is similar to that described for Arlington Heights.

San Jacinto Land Company.—The following lands, which are adjacent to the south and west boundaries of Arlington Heights, are served by the Gage canal at its extreme southwesterly terminus:

Lands of San Jacinto Land Company served by Gage canal.

	Acres.
Growing oranges	452
Growing lemons	60
Growing grape fruit	18
Total cultivated area	530
Uncultivated area	120
Total area subject to canal	650

DUTY OF WATER.[a]

The duty of water under the Gage canal system is equal to 1 miners' inch to each 5 acres of land, continuous flow. Its equivalent is 0.02 cubic foot per second, which converted into the form of an equivalent annual rainfall equals very nearly 35 inches depth of water over the whole area of land. As the periods of irrigation are generally at intervals of one month, each monthly irrigation is equal to a rainfall of nearly 3 inches.

Under this system the purchaser of land becomes a shareholder in the canal and the water sources, and by virtue of his water stock has a voice in the management of everything pertaining to the water service. The management consists of a board of directors elected annually by the owners of the lands and the stockholders in the canal company.

The portions of the by-laws which provide for the issuance of stock carrying water rights and for the distribution of the water are as follows:

ARTICLE V.

CAPITAL STOCK.

SEC. 1. The board of directors shall cause to be issued certificates of stock to subscribers or purchasers of stock or to persons with whom the corporation may bargain or contract in relation to the purchase or use of water or water rights or property of any kind or character, and shall cause such stock and certificates thereof to be issued in accordance with the direction of any of the above-named persons; and thereafter shall cause to be issued to stockholders or their assignees certificates of stock, in accordance with law and their articles of incorporation and these by-laws and rights of the parties, which certificates shall be signed by the president and secretary; and all stock (or new stock issued or to be issued in lieu thereof) sold, bartered, or exchanged for the purpose of purchasing water to be supplied to or flowing in the canal or canals used or owned by the corporation shall have attached thereto and transferred therewith and evidenced by indorsement on the certificate thereof a water right or rights to the use of water delivered at the main canal in continuous flow under a 4-inch pressure in the proportion of one-tenth of an inch under said pressure to each share: *Provided*, That the board of directors shall, in their discretion, have power to affix to such water rights when

[a] Detailed descriptions of the use and duty of water under the Gage canal system are given in Bull. 86 U. S. Dept. Agr., office of Experiment Stations, Pt. 1, p. 74, Pt. II, pp. 131-148.

the same are first granted such terms or conditions as to application or use of water for specific purposes as they may contract or see fit, and to provide that such conditions shall be observed, otherwise such water right to be void, but thereafter such terms or conditions shall not be changed except by consent of the stockholder holding such water right: *And provided also*, That such water right shall be subject to the provision of the articles of incorporation in that behalf and to these by-laws or any amendments thereof and to the rules and regulations which are or may be from time to time adopted by the board of directors. Certificates of stock shall not be issued in less amount than one share.

SEC. 2. No transfer of stock shall be binding on the corporation unless duly entered on its books, nor shall stock be issuable until the owner thereof or his duly authorized agent shall have signed a receipt therefor on the stub of the stock-certificate book and until all the previous assessments and water rates as provided by these by-laws and the articles of incorporation, levied thereon according to the law and according to these by-laws and the articles of incorporation, have been fully paid.

ARTICLE VIII.

AS TO BY-LAWS.

These by-laws, or either or any of them, by section or article, may be repealed, amended, or added to, or new by-laws adopted in their stead, either by the stockholders at any meeting thereof or by the majority of the board of directors at any meeting thereof.

ARTICLE IX.

MISCELLANEOUS.

SEC. 1. An inch of water in these by-laws referred to is defined to be a continuous flow of water through an aperture one (1) inch square under a pressure of four (4) inches, measured from the center of such aperture to the surface of the water.

SEC. 2. Each stockholder is entitled to water in continuous flow, or its equivalent, taken monthly, according to the by-laws and regulations of the corporation. Should any stockholder desire to have furnished in one day the supply of water to which he is entitled for a certain number of days not to exceed thirty days (nor in excess of the capacity of the distributing pipe or pipes to his land or lands), he shall give the corporation at least four days' notice of such desire and accept the water on any day or days that the company may be able to arrange for the supply thereof.

COST.

The cost of the system to 1893 is as follows:

Cost of Gage canal system to 1893.

Main canal and connected works, including rights of way	$285,000
Distributing pipe lines and connected works	70,000
Artesian wells	50,000
Water sources and connected lands	175,000
Total	580,000

[For index see end of Part II, Water-Supply and Irrigation Paper No. 60, which contains descriptions of the East Riverside irrigation district, the Riverside-Highland Water Company, and the lower San Bernardino Valley above Rincon, also complete data of the 890 wells in the San Bernardino and Redlands quadrangles, and notes concerning the manufacture of Portland cement in southern California.]

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DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 60

WASHINGTON
GOVERNMENT PRINTING OFFICE
1902

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

DEVELOPMENT AND APPLICATION OF WATER NEAR SAN BERNARDINO, COLTON AND RIVERSIDE, CAL

PART II

By JOSEPH BARLOW LIPPINCOTT

WASHINGTON
GOVERNMENT PRINTING OFFICE
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DEVELOPMENT AND APPLICATION OF WATER NEAR SAN BERNARDINO, COLTON, AND RIVERSIDE, CAL.

PART II.

By JOSEPH BARLOW LIPPINCOTT.

EAST RIVERSIDE IRRIGATION DISTRICT.

The lands of the East Riverside Irrigation District are 4 miles south of the city of Colton and 4 miles northeast of the city of Riverside. They are divided into approximately equal parts by the boundary line between San Bernardino and Riverside counties, and vary in elevation from about 900 feet to 1,250 feet, being situated on the mesa and bottom lands on the south side of San Bernardino Valley. These lands are specially adapted to the growth of citrus fruits. The district was organized under the Wright irrigation district act, and has had fewer misfortunes than are usual with similar enterprises. It is, however, endeavoring to disorganize. The total area of lands comprised within its boundaries (3,100 acres), 250 acres of which are hilly and rough, being partially unfit for cultivation, leaving 2,850 acres of first-class agricultural land. The irrigation district and its pipe line are shown in Pl. I (Part I). In order to obtain a water supply, in 1892 the irrigation district purchased from Garner & McKenzie 65 acres of artesian lands in the bottoms of Lytle Creek northeast of San Bernardino. Three wells were sunk in these lands, the deepest being 450 feet and the other two about 250 feet each. A cut was also run in the cienaga upon these lands, for the purpose of developing water. The development during that year (1892) produced 100 miners' inches, or 2 second-feet, at a total cost of $5,997. The output of these artesian wells, which are referred to in the description of the wells of San Bernardino Valley, is given in the table on page 36 (Part I).

In 1891 the East Riverside Irrigation District purchased a 24-inch pipe line from Raynor Springs, about 1¾ miles below the artesian land of the district, in sec. 4, T. 1 S., R. 4 W., situated within the district. This pipe line was constructed in the year 1889 by the Vivienda Water Company, for the purpose of serving the greater portion of what is now the East Riverside irrigation district. The pipe is of riveted

iron, the gage ranging from No. 10 to No. 14 Birmingham standard. The maximum pressure per square inch sustained by the different sizes as the pipe was constructed was: No. 14, 30 pounds; No. 12, 71 pounds; No. 10, 110 pounds. The valley hydraulic grade line is 7 feet to the mile, and the discharging capacity 9 cubic feet per second.

After the consummation of the purchase by the district the pipe line was extended 8,100 feet, to the wells that had previously been sunk. The upper portion of the pipe is of steel, No. 14 gage. The reservoir was constructed on the lands purchased. It is 40 feet by 70 feet on the bottom, has a depth of 5 feet, and is cement lined. Two kinds of pipe were used in the distribution system—riveted steel and vitrified clay. In 1892 it was estimated that distribution by this means would cost $15 an acre.

The following are the amounts expended in the construction, with the value of the assets, the purchase of the 24-inch pipe line being included in both statements, which are taken from the report by F. C. Finkle, engineer for the district in 1892:

Expenditures.

Purchase price of Vivienda pipe line	$100,000.00
Extension, 8,100 feet to Vivienda pipe line	23,642.87
Two lateral pipe lines	2,292.10
Reservoir No. 2 (when completed)	1,210.00
Cost of sinking three artesian wells	4,497.00
Drainage cuts to McKenzie Spring	500.00
Total	132,141.97

Value of assets.

24-inch conduit as extended	$123,642.87
Two lateral pipes	2,292.10
Reservoir No. 2	1,210.00
100 inches (2 cubic feet) of water, at $1,000 per inch	100,000.00
Total	227,144.97

The owners of the Vivienda Water Company claim that the pipe line, which they value at $100,000, actually cost $120,160, divided as follows:

Pipe-line material and laying	$96,000
Trenching and back filling	8,000
Right to suspend line on motor bridge	1,000
Bridge across Santa Fe Railroad cut on Third street	360
Engineering and superintendence	3,400
Three miles of cement ditch, including pipe across Little Terquisquite Arroyo	11,400

The cement ditch lines referred to were also transferred to the irrigation district.

RIVERSIDE-HIGHLAND WATER COMPANY.

The Riverside-Highland Water Company is a corporation organized February 21, 1898, under the laws of California, to furnish water for domestic purposes and the irrigation of the lands of shareholders situated in that portion of the East Riverside irrigation district in Riverside County which is known as Highgrove. The capital stock was $200,000, divided into 5,000 shares of $40 each. The policy of the company is to furnish an abundance of water to irrigate 2,500 acres of land at the rate of 1 miners' inch of water measured under a 4-inch pressure for each 5 acres of land for the growing of citrus orchards. Recently the company, by a vote of its stockholders, reduced its capital stock to $100,000, divided into 2,500 shares, of which a little more than 2,300 shares are subscribed for and more than 50 per cent is paid in.

The company is the owner of 157 acres of artesian water-bearing lands a few miles north of Colton, in San Bernardino County, from which the water is conducted in a long underground cement and iron pipe line to the lands of its stockholders at Highgrove, a distance of a little more than 7 miles. On these water-bearing lands there are a number of deep artesian wells, from five of which all of the water now used by the company, amounting to a little more than 300 miners' inches, is pumped by means of one 22-horsepower gas engine and two 30-horsepower electric motors, the electric current being furnished at a cost of 1½ cents per horsepower per hour by the Redlands Electric Light and Power Company. The pumps used are of the centrifugal type.

The company does not know how much water its lands will furnish, but it believes that it has an abundant supply. It is now furnishing sufficient water to meet all the demands of 1,800 acres of both old and young orchards, and so far no one has hesitated on account of lack of water to plant orchards in the territory covered by the company. The water is delivered to consumers on demand upon the payment of a toll of 10 cents per miners' inch for a twenty-four hours' run. The lands watered by the company are at a higher elevation than those watered by any other company in the Riverside district, hence its name. The orchards watered are relatively free from frost.

The East Riverside Irrigation District still exists, with its board of officers, but is not operating its system, the Riverside-Highland Water Company supplying water to such portion of the lands as the owners have become stockholders in its company, also to other lands. The landowners within the East Riverside irrigation district, after an effort of eight years, found it impracticable to carry on the system under the act of the legislature popularly known as the Wright act, owing to the fact that the act provided that the revenue should be raised by annual taxation, and also to the extreme difficulty experienced in collecting the taxes thus levied, resulting in numerous tax sales

and in suits to restrain the execution of tax deeds by the owner just before the expiration of the redemption period. These suits were expensive to the district, in many instances costing more to defend than the taxes were worth when collected, and resulting in vexatious delays and appeals to the higher court. When no redemption was made from tax sales the tax deeds were executed and delivered to the district, which invariably had to become the purchaser, for no private person would venture to purchase at the sales for fear of expensive litigation to protect the titles procured. In this way a large tract of unimproved land owned by divers and sundry persons, both residents and nonresidents, became conveyed to the district, and while the law authorized the district as owner to sell the lands at their market value, no purchaser could be found who was willing to buy them under the titles held by the district. The lands subject to taxation diminished every year to such an extent that it became manifest that the entire revenue of the district for the payment of its obligations—interest on bonds, operating expenses, etc.—would have to be met by the few landowners who were faithful in paying their taxes; hence the landowners, for self-protection, organized the Riverside-Highland Water Company and ceased to operate as the East Riverside Irrigation District.

LOWER SAN BERNARDINO VALLEY ABOVE RINCON.

Santa Ana River is the most important stream of southern California west of the Coast Range. It includes among its tributaries all of the streams entering San Bernardino Valley, and drains a total area above Rincon of 1,463 square miles, including valley lands, exclusive of the lands tributary to Lake Elsinore; 555 square miles of the basin are mountainous. San Bernardino Valley proper contains 525 square miles.[a] There is a secondary coast range lying along the western edge of the valley, through which Santa Ana River cuts a canyon, beginning at Rincon, which is the railroad station of Crary. These hills are of a shale and sandstone formation of more recent geologic origin than the main range to the east, and constitute a dam or dike which concentrates and throws to the surface most of the underflow or seepage water proceeding through the valley toward the sea. This produces a greater volume of water in the river at Rincon during the irrigation season than at any other place along the stream. During the summer there is a larger body of water flowing at Rincon than at any other place in California south of the Tehachapi Mountains, except in Colorado River.

The streams surrounding San Bernardino Valley have drainage basins which are exceedingly steep and are poorly supplied with forest cover. The basin above Rincon is of granite origin. The storms which occur in southern California are frequently violent, and falling on these drainage basins produce torrential floods which rush onto

[a] For details of these drainage areas see Part I, pages 51 and 52.

the plains, carrying large quantities of granitic detritus. In this way San Bernardino Valley has been built up. These great beds of gravel and bowlders have a high percentage of voids, the porous space being probably one-third of the mass. Consequently the floods which are projected upon the plains are rapidly absorbed, and the great underground reservoir, with a controlling outlet at Rincon, the storage capacity of which is very great, is filled.

If an area of gravel of 500 square miles should be charged to a depth of 300 feet its storage capacity would be 32,000,000 acre-feet of water. These figures are given merely to suggest the enormous capacity of this great underground storage reservoir of San Bernardino Valley. It has been charged with waters through a long cycle of years by the floods described. In addition to the winter floods the summer flow of all the streams from San Antonio Creek to Mill Creek is diverted and used for irrigation purposes, and probably 50 per cent of it sinks into the ground and reenforces the water plane. This large underground reservoir slopes toward Santa Ana River, and its surplus waters are brought to the surface in the canyon at Rincon. The velocity with which the water passes through the gravels is undoubtedly very slow and varies with the density of the soil and the steepness of the slope, causing a very constant delivery of water at the Rincon Narrows.

In June, 1898, a series of measurements was made to determine the relation between the water flowing on the surface of the ground at the mouths of the various mountain basins entering San Bernardino Valley and that returning into the channels of the Santa Ana in the central portions of the valley. The following approximate results were obtained:

Discharge measurements in San Bernardino Valley, 1898.

Stream.	June.	September.[a]
	Second-ft.	*Second-ft.*
Mountain streams above Slover Mountain	80	63
Mountain streams below Slover Mountain	21	17
Total summer streams from mountains	101	80
Return and developed water above Slover Mountain	[b] 138	[b] 145
Return water between Slover Mountain and Riverside Narrows	75	62
Return water between Riverside Narrows and Rincon	61	53
Total return water above Rincon	274	260

[a] Measurements made between August 27 and September 9.
[b] Riverside Water Company's lower canal not included.
NOTE.—One second-foot equals 50 California miners' inches.

From the foregoing table it will be seen that in June, 1898, there were 173 second-feet, or 8,650 miners' inches, and about September 1 180 second-feet more water seeping into the channels of Santa Ana River in the central portion of the valley than there was entering the valley from the mountain drainage basin.[c] The amount of water rising in the central portion of the valley was about three times the amount

[c] For details see page 47, Part I.

that was being furnished from the mountain streams. During the winter season the mountain streams are much larger in volume. In the case of San Gabriel River, in June, 1898, there was a total of 16 second-feet of water entering from mountain drainage basins above Puente, and 62 second-feet were found flowing in The Narrows, where San Gabriel River cuts through the same secondary coast range that the Santa Ana encounters at Rincon. A similar condition exists opposite Tropico, on Los Angeles River, where in June, 1898, there were 68 second-feet of water flowing and no water entering from the surrounding mountain drainage basins.

The amount of water which returns from irrigation into the channel of the Santa Ana below the lands irrigated is known to be large. According to tables which have been prepared by Prof. L. G. Carpenter, in charge of the Colorado experiment station at Fort Collins, Colo., the velocities of underground water are found to be less than 1 mile a year under ordinary conditions. It will therefore require a number of years for return irrigation water which, for instance, is used in the neighborhood of Rialto or Riverside to reach the channel of Santa Ana River. During the summer of 1899 Mr. Cyrus C. Babb, a hydrographer from the United States Geological Survey, made a determination of the amount of water returning from irrigation in the Solomonsville Valley, on Gila River, Arizona, and found that a volume equaling 64 per cent of the amount which was being used for irrigation at that time was returning to the stream; in the neighborhood of Phoenix the amount returning was found, in a similar manner, to be 40 per cent. In Ogden Valley, Utah, on Ogden River, Prof. Samuel Fortier determined, as the result of thirteen measurements made in the summer of 1894, that while the inflow into the valley was 98.9 second-feet the amount used for irrigation was 76.3 second-feet and the outflow was 115.9 second-feet, showing a greater amount returning than was being used at that time for irrigation. This was doubtless due to the fact that greater quantities of water were used for irrigation in the spring than during the summer months. In Colorado, on Cache la Poudre River, Professor Carpenter, as a result of extensive measurements and experiments, has drawn the following general conclusions:

(1) There is a real increase in the volume of the streams as they pass through the irrigated sections.

(2) The inflow is practically the same throughout the year. It is greater in summer and less in winter, principally because of the effect of the temperature on the soil.

(3) The passage of the seepage water through the soil is very slow, so that it may take years for the seepage from the outlying lands to reach the river.

(4) The seepage water is already an important agricultural factor of the State. The capital value of the water thus received in the valley of the Cache la Poudre alone is not less than $300,000, perhaps $500,000, and for the Platte it is from $2,000,000 to $3,000,000. It is large for the other streams, but of unknown amount.

(5) Ultimately the returns from seepage will make the lower portions of such

valleys as the Platte more certain of water and will probably permit a larger acreage to be grown.

(6) The results here shown may be expected to apply, with limitations, to other valleys similarly situated, where irrigation is as copious, crops the same in character, and the subsoil and rock strata similar and at approximately the same inclination. Where the soil is less porous a greater time must elapse for the water to percolate.

At Rincon there is a flat of approximately 4 square miles area immediately above the canyon, which is believed to contain gravel and sand to depths of at least 50 or 60 feet, below which alternate layers of clay and gravel are believed to exist. Approximately one-third of this area lies on the south or left bank of the river and the remaining two-thirds on the north bank.

Numerous measurements have been made from the Riverside Narrows through to Olive, and the maximum volume of water that occurs at any point in the river is believed to be at the wagon-road crossing of the stream near Rincon.

In the following table is given a series of measurements made by the United States Geological Survey approximately 1 mile below the railroad bridge crossing Santa Ana River below Rincon, the measurements having been made at that point until September 29, 1899, since which date they have been made at the wagon bridge. On September 13, 1899, it was found that when there were 74.38 second-feet of water at the Geological Survey gaging station there were 76.61 second-feet of water at the wagon bridge, or 2.23 feet more water at the wagon bridge than at the Geological Survey station. The wagon bridge being the point of maximum flow, subsequent measurements were made there.

Discharge measurements of Santa Ana River and canal near Rincon, below the mouth of Chino Creek.

Date.	Hydrographer.	Discharge of river.	Discharge of canal.	Total discharge.
1898.		*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
June 21	F. H. Omsted	79.81	3.18	82.99
1899.				
January 3	S. G. Bennett	209.40	2.30	211.70
January 16	F. Rolfe	231.90	0.00	231.90
January 28	do	216.00	6.50	222.50
February 15	do	181.00	1.75	182.75
March 4	do	108.60	0.00	108.60
March 18	do	199.89	0.00	199.89
April 6	do	172.23	0.00	172.23
April 18	do	101.10	2.75	103.85
May 2	do	100.34	2.45	102.79
May 15	do	100.36	3.95	104.31
June 3	do	110.27	3.18	113.45
June 16	S. G. Bennett	87.89	1.65	89.54
July 4	F. Rolfe	68.89	2.42	71.31
July 18	do	64.13	1.54	65.67
August 1	do	57.82	3.44	61.26
August 15	do	64.71	3.16	67.87
August 30	S. G. Bennett	65.90	2.00	67.90
September 13	J. B. Lippincott	72.73	1.65	74.38
September 29	F. Rolfe	83.82	0.00	83.82

Discharge measurements of Santa Ana River at wagon bridge above the mouth of Chino Creek.

Date.	Hydrographer.	River.	Chino Creek.	Springs.	Total discharge.
1899.		*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
October 25	J. B. Lippincott	131.32	14.52	0.50	146.34
October 26	do	146.53	14.52	0.50	161.55

Discharge measurements of Santa Ana River at Riverside Narrows, below all Riverside diversions and north of Arlington Heights.

Date.	Hydrographer.	Discharge.
1898.		*Sec.-ft.*
June 20	F. H. Olmsted	47.63
August 29	do	39.05
1899.		
July 17	F. Rolfe	31.70
September 12	J. B. Lippincott	39.69

For the purpose of comparison four measurements of the amounts of water flowing at Rincon and at the division box of the Santa Ana and Anaheim irrigation companies were made on the same dates, with the results shown in the following table:

Discharge measurements of Santa Ana River.

Date.	Hydrographer.	U. S. G. S. gaging station below Rincon.	Division box of Santa Ana and Anaheim irrigation companies.
1898.		*Sec.-ft.*	*Sec.-ft.*
June 21	F. H. Olmsted	79.81	67.47
1899.			
August 30	S. G. Bennett	65.90	59.62
September 13	J. B. Lippincott	72.73	71.68
October 25	do	[a] 146.34	144.72
Total discharge		364.78	343.49

[a] Measured at Rincon wagon bridge.

At the time of the first three measurements there was flowing in a ditch on the left bank of the river opposite the gaging station 3.18, 2, and 1.65 second-feet of water, respectively, which is not included in the totals given in the foregoing table. If included it would show a still greater quantity of water at Rincon. The average of the measurements indicates the presence of 5.32 second-feet (266 miners' inches) more water at Rincon than at the division box. If the greater amount of water found at the Rincon wagon bridge, as compared with that at the original gaging station, is considered, as well as the diversions of the ditch on the left bank opposite the original gaging station, then it is shown by these measurements that there is

a loss of fully 8 second-feet between the Rincon wagon bridge and the division box of the Santa Ana and Anaheim water companies. On September 13, 1899, there were at the Rincon bridge 76.61 second-feet of water, while in the two canals of the Santa Ana and Anaheim companies, at a point opposite Esperanza Siding and above all irrigation from either canal, there were only 58.68 second-feet of water, showing a loss of 17.93 second-feet (896 miners' inches) between those points. On October 26, 1899, there were 161.55 second-feet of water at the Rincon bridge and 122.37 second-feet in the canals and river opposite Esperanza, the total amount in the canals being 73.21 second-feet. This shows a loss of 39.18 second-feet (1,959 miners' inches). These measurements are not given as absolute, but they were the best possible determinations under existing conditions. The fact that a loss is shown by each of the observers mentioned is considered evidence that a loss exists and that it is large. Additional measurements are desirable in order to determine more definitely the amount of this loss.

An examination of the wells in the vicinity of Rincon was made in connection with the investigation. As a result it is believed that a bed of gravel, cobble, and sand 40 feet deep exists on the south side of the river, that it is porous and filled with water, and that development works of proper size and form could obtain from it a large supply. From the Auburndale bridge to the Rincon bridge the river gains 12.75 second-feet of water, as indicated by the measurements of September, 1899, Chino Creek not being considered. An examination of the records of wells north of the river indicates that a blanket of clay slopes from the neighborhood of Chino toward the south. Artesian wells occur in the neighborhood of Chino, and flowing water is obtained as far south as the Pioneer schoolhouse, which is approximately 3 miles north of the land referred to. In a well on the property of Mr. Durkee, approximately 1 mile north of this land, a blanket of hard clay 20 feet thick was encountered at a depth of 47.5 feet from the surface of the ground. Beneath this was coarse gravel. The water in this well rose to within a few feet of the surface of the ground. The well furnishes a supply which has never been exhausted by the demands upon it.

Mr. Durkee states that similar conditions were encountered at the schoolhouse well. From the Auburndale bridge to Chino Creek springs are found on both sides of the valley. The evidence obtained from the wells indicates that a blanket of clay may be found in the gravel beds near Rincon. If this layer of clay exists, beneath it will be found large bodies of water, which can be pumped extensively if they do not flow naturally, and the water supply be increased thereby. The only evidence to the contrary that was found was at the pipe works, approximately 3 miles southeast of Rincon, where indefinite information was obtained that two wells have been put down, one 500

and the other 600 feet in depth, through sandstone, bowlders, and gravel, without encountering a layer of clay. The water in these wells, however, rose to within 25 feet of the surface, and the supply has been found sufficient to meet all demands upon it. The elevation of these wells at the surface of the ground is approximately 100 feet above the river at Rincon. At the foot of the small mesa which immediately joins the town on the south shallow wells have been put down to a depth of 25 or more feet, from which flowing water has been obtained.

If development works can be located which will permit the lowering of the water plane 21 feet beneath the surface of the ground, where it now stands, over an area of 1,000 acres, sufficient water could be obtained to furnish 1,000 miners' inches for a period of six months. It has previously been shown that there enters the river naturally from the eastern end of the valley to the Rincon bridge, inclusive of Chino Creek, approximately 700 miners' inches. This increase indicates a supply which is constantly approaching these lands and which should be an addition to the storage capacity of the gravel mentioned. It is believed, therefore, that from 1,500 to 2,000 miners' inches of water could be obtained if development works were constructed which would permit the lowering of this water plane each season 21 feet over an area of 1,000 acres. In a gravel bed west of Burbank the West Los Angeles Water Company has constructed a cut approximately 3,000 feet in length, which varies in depth from nothing to about 25 feet, and which is now delivering, at the end of the drought of 1900, in the neighborhood of 300 miners' inches of water in a locality which is not so favorably situated for the purposes of developing water as are the lands referred to. The works of the West Los Angeles Water Company consist of an open cut in which is placed a wooden flume with sides and top but without bottom. The water enters the flume principally through the bottom. These development works have been in operation since the fall of 1895 and have maintained a continuous discharge of water, although the water plane of San Fernando Valley has been steadily falling.

The Crystal Springs Water Company has laid approximately 2,000 feet of sewer pipe, with open joints, in the sandy bed of Los Angeles River in the narrows west of Verdugo. There are four pipes, laid in two cuts, which are collecting from 400 to 500 miners' inches of water from the river bottoms.

Broadly speaking, the method of procedure should be to divert the entire flow of Santa Ana River near the Auburndale bridge at the beginning of the irrigation season, say the first of May, and carry it in a lined conduit to a point west of Rincon where a drop could be obtained which would produce a substantial water power. The water stored in the gravel beds should then be drawn down by means of pumps operated by this power. At the end of the irrigation season

the pumps could be stopped and the water be returned to the natural bed of the river between the Auburndale bridge and Rincon during the season of the year when the supply is large and when the loss to the river in recharging these beds, in addition to the natural inflow of water returning from irrigation, would not be felt. In this manner the storage capacity of the gravel beds would be available the following spring, when the water plane could again be drawn down. Any artesian water that might be found would be in addition to the water obtained from the pumps.

Summarizing, the following conclusions have been reached:

(1) That a large percentage of water used for irrigation returns to the channels of the streams, the amount being greater where the soil is porous and the slopes are steep, both of which conditions exist in San Bernardino Valley.

(2) That the movement of the water through the soil is exceedingly slow, and that while the increase due to irrigation is now felt at Rincon the volume of return water from irrigation will increase in the future and will be a permanent source of supply.

(3) Water of this character is now making its appearance on the lands near Rincon. This is indicated by the fact that although we are now practically at the end of a nine-years' drought the water plane of these lands has steadily risen, until orchards, vineyards, and alfalfa fields which are said to have previously flourished have been drowned. Around Riverside alone 5,000 miners' inches (100 second-feet) of water are now being used for irrigation.

(4) It is impossible to determine accurately the amount of water that could be gathered. It is believed, however, that about 2,000 miners' inches or more could be obtained by pumping. This amount would be independent of any supply which would be obtained from artesian wells.

(5) That the stream measurements show a loss between Rincon and the head of the Santa Ana canal near Esperanza of about 800 miners' inches, which might be saved by a lined conduit extending down the canyon about 7.4 miles.

WELLS IN REDLANDS AND SAN BERNARDINO QUADRANGLES.

All of the wells in the Redlands and San Bernardino quadrangles, irrespective of size or producing capacity, were visited by representatives of the Geological Survey during the summer of 1900. There were 412 wells in the Redlands quadrangle, which were inspected by Mr. Louis Mesmer, of Los Angeles, and 478 wells in the San Bernardino quadrangle, which were inspected by Mr. C. J. Roney, of the same city. The results of the observations were described with considerable detail in the field record books, but have been condensed for publication in this report and are given in the following tables. The

numbers of the wells in the tables correspond with those on the map (Pl. I, Part I) and are the same as those given to the detailed descriptions in the field record books. The principal facts are stated in abbreviated form. In the first column is the number of the well as shown on the map. In the next column is the name of the owner, and following that the location, by township, range, and section, the date completed, and the class of well, the latter being indicated by established symbol, *D* meaning dug well, *Dr* driven well, *B* bored well, and *H* horizontal well or tunnel, the accompanying figures giving the size in feet and inches. The elevation of the surface of the well, the elevation of water in the well, and the depth of the well in feet are given in the next columns. The character of the strata is indicated by initials, *C* meaning clay, *G* gravel, *B* bowlders, *L* loam, *S* sand, *R* rock, and *Hp* hardpan. To illustrate: *LSG* is equivalent to loam, sand, and gravel. The next column gives the quality of water, whether hard, soft, alkaline, or sulphurous. The next one gives the method by which the water is obtained, the word *hand* meaning hand pump, *horse* a horsepower machine, *electric* an electric motor, *centrifugal* a centrifugal pump, *gas* a gasoline engine, *wind* a windmill, etc. In the case of the windmill the accompanying figures give the diameter of the windmill in feet. For example: *14 wind* is intended to imply that water is pumped by a 14-foot windmill. In the case of the gasoline engines, electric motors, etc., the accompanying figures indicate the horsepower. The cost of the well and of the machinery (the latter is only roughly approximate) is given in the next two columns, and after that the quantity of water, usually in second-feet, but where otherwise *good* indicates a good supply and *small* a small or deficient supply. In many instances, particularly with capped artesian wells connected directly with pipe systems, it was difficult to determine the volume of water that the well was discharging. In a few instances, which are indicated, the volumes given are for other years than 1900. In the column headed "use of water" the abbreviation *dom* implies domestic use, *st* implies use for watering cattle and horses, and *irr* that water is used for irrigation. Topographic maps were used in determining the elevation of the ground at the well, and the depth to water having been measured with a tape the elevation of the water plane was determined accordingly. The elevations all refer to the summer of 1900, and undoubtedly will vary substantially, either owing to the excessive pumping of water or to subsequent wet years.

Wells in Redlands quadrangle.

No. of well.	Owner	Location (T.R.S.).			Year completed.	Class of well.	Elevation of surface.	Elevation of water.	Depth of well.	Strata.	Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
		S.	W.				Feet.	Feet.	Feet.						Sec.-ft.	
1	Dr. Meeker	1	2	16	1900	D, 4 by 6 feet	1,995	1,718	180	CG			$1,100			
2	Ward, Mills & Co	1	2	21	1900	D, 4 by 6 feet	2,005	1,933	125	CG		Gas	750			
3	Crafton Water Co	1	1	7	1900	D, 5 by 6 feet	3,010	2,992	132	BG		Centrifugal; electric	2,000	$2,500	1.38	Irr; power.
4	do	1	1	8	1900	D, 5½ by 6½ feet	3,650	3,648	98	GR		do	[a] 6,000	2,500	2.70	Irr; power.
5	Mrs. M. A. Brown	1	2	22	1879	D, 4 by 4 feet	2,250	2,225	27	Gravel	Hard	Wind		100		Dom.
6	Geo. McIntosh	1	2	22	1899	D, 4 by 4 feet	2,230	2,189	70	Gravel		Centrifugal; electric				Irr.
7	R. P. McIntosh	1	2	20	1900	D, 4½ by 4½ feet	1,910	1,818	103	SGB	Soft	Cylinder pump; gas.	700	925	0.14	Irr.
8	L. Lodge	1	2	16	1900	D, 4 by 6 feet	2,060	2,050	70		do	do		1,500	0.30	Irr.
9	L. Lyons	1	2	16	1900	D, 4 by 6 feet	2,075	2,052		GB		do				Irr.
10	T. P. Christian	1	2	17	1900	D, 4 by 6 feet	1,900	1,748	180	CBSG	Soft	do		1,500		Irr.
11	F. Wieder	1	2	29	1900	D, 4 by 5 feet	1,830	1,779	100	GBC	do	do	450	950		Irr.
12	E. J. Roberts	1	2	28	([b])	D, 4 by 6 feet	2,200	2,192				Horse	300			Irr.
13	H. H. Garstin	1	2	29	1900	B, 10 inches	2,000	1,905	241	CG	Soft	Cylinder pump; gas.	800	1,430	0.06	Irr.
14	W. J. Tench	1	2	19		D, 4 by 6 feet	1,720	1,560	163	SGB						Irr; dom
15	East Redlands Water Co.	1	3	36	1900	B, 12 inches	1,805	1,621	514			Cylinder pump; gas.	2,200		0.32	Irr.
16	E. & D. Conkling	1	2	31	1899	B, 10 inches	1,795	1,545	350		Hard	do		2,200	0.40	Irr.
17	M. S. Crosswell	1	3	24		D, 4 by 6 feet	1,540	1,378	163	Gravel	Soft	do			0.12	Irr.
18		1	2	33		D, 2½ by 4 feet	2,120	2,060	60							
19	Mr. Gregory	1	2	33	1892	D	2,130	2,123	10			Hand	20			Dom.
20	Dunlap estate	2	2	4	1899	B, 10 inches	2,040	2,040				Centrifugal; gas			0.50	Irr.
21	do	2	2	4	1895	B, 7 inches	2,075	2,077	142			Artesian			0.005	Dom.
22	do	2	2	4	1900	B, 10 inches	2,100	2,100	800	CGS	Hard	do	2,950		0.015	Irr.
23	do	2	2	4	1900	B, 10 inches	2,090	2,090		CSG	do	do				Irr.
24	Houghton & McNee	2	2	4	1895	D, 3 by 4 feet	2,270	2,227	43	Gravel		Wind				Dom.
25	Geo. Clyde (tunnel)	1	2	26		H, 4 by 6 feet	2,700	2,700	97	Porphyry		Gravity	[c] 300		0.02	Irr; dom.
26	Mr. Biggin	1	2	34	1899	D, 6 by 6 feet	2,224	2,163	65	SG					0.16	
27	South Mountain Water Co.	1	2	33	1900	B, 10 inches	2,160	2,132	300+			Centrifugal; steam				Irr.
28	Garland estate	1	3	25	1900	B, 10 inches	1,570	1,364		CG		Cylinder pump; gas.				Irr.
29	C. D. Fowler	1	3	5	1891	B, 10 inches	1,180	1,125	70	SG	Hard					
30	West Redlands Water Co.	1	3	35	1899	B, 12 inches	1,600	1,530	226	GCB	do	Cylinder pump; gas.	1,250	2,500	0.40	Irr.
31	do	1	3	35	1899	B, 10 inches	1,620	1,529	248	GCB			1,080			Irr.
32	do	1	3	35	1899	B, 12 inches	1,626	1,536	243	GCS		Cylinder pump; gas.	1,700	2,500	0.36	Irr.
33	Redlands Heights Water Co.	2	3	1	1900	B, 10 inches	1,880		300	CSG			1,200			Irr.
34	Mr. Painter (?)	2	2	8	1899	D, 4 by 6 feet	1,975	1,932	60	Gravel						
35	do	2	2	8	1899	D, 4 by 6 feet	1,975	1,962	46	Gravel						

[a] Well and tunnel 250 feet long. [b] Not completed. [c] Tunnel 97 feet long.

Wells in Redlands quadrangle—Continued.

No. of well.	Owner.	Location (T. R. S.).			Year completed.	Class of well.	Elevation of surface.	Elevation of water.	Depth of well.	Strata.	Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
		S.	W.				Feet.	Feet.	Feet.						Sec.-ft.	
36	Mrs. Diaz	2	3	14		B, 7 inches	1,545	1,456	96			Hand	$125	$20		Dom.
37	C. W. Blue	2	3	14	1898	B, 7 inches	1,523	1,455	110	Gravel	Hard	Wind	200	75		Dom; irr.
38	A. Gregory	1	3	27	1895	B, 7 inches	1,379	1,274	168	CRGS	do	do	250	500	0.016	Dom.
39	W. McConkey	1	3	27	1898	B, 7 inches	1,380					do				Dom.
40	D. Madell	1	3	27	1898	B, 7 inches	1,377	1,277	171		Hard	do	274		0.001	Dom.
41	G. H. Garland	1	3	26	1899	B, 10 inches	1,450	1,261	246	GC		Cylinder pump; gas.		3,000	0.40	Irr.
42	C. L. Hayes	1	3	27	1899	B, 10 inches	1,420	1,270	428	CGSB	Soft	do	850	1,400	0.30	Irr.
43	O. W. Harris	1	3	34	1895	B, 7 inches	1,508	1,308	312	CSG	Hard	Cylinder pump; electric.	600	800	0.075	Irr; dom.
44	Horace Evans	1	3	33	1899	B, 10 inches	1,455	1,259	660	CG	Soft	Cylinder pump; gas.	1,900	1,400	0.18	Irr; dom.
45	A. C. Fowler	1	3	32	1898	B, 9 inches	1,250	1,140	170	SGC	do	do	250	300	0.10	Irr.
46	L. C. Smith	1	3	32	1898	D, 3 by 3 feet	1,215	1,135	83	Gravel	Hard	Wind	90	65	0.003	Dom.
47	P. B. Fussell	1	3	32	1897	B, 12 inches	1,253	1,195	165	SGC	Soft	do	330	230		Irr; dom.
48	E. Vaché	1	3	32	1885	B, 7 inches	1,260	1,200	140		Hard	do	170	75		Dom.
49		2	3	4	1893	B, 7 inches	1,350	1,290	150			do				St.
50	W. D. Covington	2	3	4	1893	B, 7 inches	1,325	1,290	157		Hard	Hand	350	20	Small.	St.
51	do	2	3	4	1893	B, 10 inches	1,300	1,300	750		do	Artesian	2,000		0.002	Dom; st.
52	D. S. Jordon	2	3	4	1899	B, 7 inches	1,395	1,379	56	LSGC	do	Wind	80	90	0.001	Dom; irr.
53	Redlands Domestic Water Co.	1	3	35	1899	B, 10 inches	1,560	1,508		CSG	do	Centrifugal; electric.	1,800		0.80	Dom; irr.
54	Wood, Bill & Davis	1	3	33	1899	B, 10 inches	1,305	1,225	462	CGS	Soft	Cylinder pump; gas.	1,200	1,800	0.40	Dom; irr.
55	D. H. Gillan	1	3	32	1899	B, 8 inches	1,245	1,157	438		do	Air compressor; gas.		3,000	0.50	Dom; irr.
56	H. Bermudas	1	3	32	1893	B, 7 inches	1,210	1,156	112		Hard	Hand		3		Dom.
57	N. B. Hinckley estate	1	3	32		B, 10 inches	1,177	1,021	700+			Wind				Dom; irr.
58	Wm. Curtis	1	3	30	1885	B, 10 inches	1,144	1,076	76		Hard	do	150	100	0.002	Dom.
59	E. C. Curtis	1	3	29	1895	B, 7 inches	1,120	1,070	96		do	do	160	75	0.002	Dom.
60	R. T. Curtis	1	3	29	1895	B, 7 inches	1,123	1,073	86	GC	do	do	140	100	0.003	Dom.
61	W. M. Curtis	1	3	29	1899	B, 12 inches	1,125	1,079	415	CG	Soft	Cylinder pump; gas.	900	1,800	0.70	Irr.
62	N. B. Curtis	1	3	29	1895	B, 7 inches	1,126	1,076	84		Hard	Wind	140	60	0.001	Dom.
63	N. B. Hinckley estate	1	3	30	1899	B, 36 inches B, 11 inches	1,150	1,108	65 271	Gravel	do	Centrifugal; gas.	900	800	0.42	Irr.
64	L. & M. Frink	1	3	30	1889	B, 7 inches	1,140	1,112	62	LSGC	do	Wind	100	163		Dom.
65	Mrs. P. S. Stewart	1	3	30	1898	B, 7 inches	1,144	1,109	76	CG	do	do	150	65	0.001	Dom.
66	Gansnor & Renwick	1	3	30	1898	B, 7 inches	1,140	1,110	200		Soft	do	320	90	0.003	Dom; irr.
67	Redlands Water Co.	1	3	35	1899	B, 10 inches	1,563				Hard	Centrifugal; electric.				Irr.
68	Mrs. M. Robison	1	3	30	1870	D, 3 feet	1,110		24		do	Hand			Dry.	
69	Southern Pacific R. R. Co.	1	3	31	1890	B, 7 inches	1,176	1,116	75		do	do	145	20		Dom.
70	W. F. Whittier	1	3	31	1898	B, 10 inches B, 7 inches	1,410	1,208	294 212	LCG	Soft	Cylinder pump; gas.	1,000	985	0.14	Dom; irr

71	do	1	3	31	1898	B, 14 inches B, 10 inches	1,150	1,108	276 84	Gravel	do	Force pump; gas	1,020		0.80	Irr.
72	Owen Buchanan	1	3	31	1898	B, 7 inches	1,265	1,149	237	LSGC	do	Cylinder pump; gas.	379	800	0.14	Irr.
73	W. J. Lawrence	1	3	31	1898	B, 7 inches	1,230	1,148	190	LCG	do	do	304	700	0.12	Irr.
74	Frink Bros	1	3	30	1899	B, 36 inches B, 10 inches	1,147	1,105	335		Hard	Centrifugal; gas	800	700	0.62	Irr.
75	Rhoda Wilson	1	3	30	1899	B, 7 inches	1,138		59	CG	do	Wind	95	65	0.001	Dom.
76	D. Van Leuven	1	3	30	1900	B, 9 inches	1,132	1,098	63		do	Hand	65	14		Dom.
77	E. Hankins	1	3	28	1899	B, 12 inches	1,254	1,200	290	Gravel	do	Cylinder pump; gas.	800	1,300	0.40	Irr; dom.
78	J. A. Osborn	1	3	28	1899	B, 10 inches	1,225	1,173	320	LGC	do	Centrifugal; gas	880		0.50	Irr; dom.
79	do	1	3	28		B, 7 inches	1,224	1,174	190	LGC	do	Wind	300	72	0.001	Dom.
80	Mrs. S. W. Sylvera	1	3	29	1891	B, 7 inches	1,200	1,170	90			do		80	0.001	Dom.
81	A. B. Cook	1	3	29	1897	B, 10 inches	1,206	1,166	110	LSG	Soft	Centrifugal; gas	220	800	0.40	Dom; irr.
82	S. Mansfield	1	3	29	1900	B, 10 inches	1,195	1,163	340	Gravel						
83	do	1	3	29	1890	B, 7 inches	1,193	1,154	109		Hard	Wind	175		Small.	Dom; irr.
84	A. Lenanon	1	3	29	1895	B, 7 inches	1,186	1,156	130		do	Cylinder pump; horse	208	40		Dom.
85	John Furney	1	3	29	1890	B, 7 inches	1,179	1,139	60		do	Wind	100	150	0.008	Dom; irr.
86	Barton Land and Water Co.	1	3	29	1891	B, 7 inches	1,180	1,137	68		do	Hand	100			Dom.
87	M. D. Easton	1	3	29	1890	B, 7 inches	1,121	1,101	45		Soft	Wind	80	70	0.008	Dom.
88	Barton Land and Water Co.	1	3	29	1891	B, 7 inches	1,130	1,100	48		Hard	Hand				Dom.
89	J. R. Campbell	1	3	29	1898	B, 7 inches	1,190	1,155	108		do	do	190	25		Dom.
90	Carl Furst	1	3	29	1891	B, 5½ inches	1,215	1,180	114		do	do	165	35		Dom.
91	S. E. Rockwell	1	3	29	1900	B, 10 inches	1,200	1,170	356	SGR	Soft	Cylinder pump; gas.	1,000	860	0.34	Irr.
92	J. Hickey	1	3	29	1898	B, 9½ inches	1,226	1,190	152	GC	do	do	314	700	0.20	Irr; dom.
93	B. M. James	1	3	29	1899	B, 10 inches	1,230	1,198	220	LSGC	do	do	418	900	0.34	Irr; dom.
94	W. A. Nichols	1	3	28	1891	B, 7 inches	1,246	1,194	122			Hand				Dom.
95	do	1	3	28		B, 10 inches	1,255	1,208	284	GCSR		Cylinder pump; gas.	580	1,000	0.36	Irr.
96	W. D. Tobey	1	3	29		B, 10 inches	1,204		324			do				Irr.
97	S. A. Grover	1	3	28	1899	B, 10 inches	1,253	1,183	231	SC	Hard	do	700	1,100	0.40	Dom; irr.
98	Schee Bros	1	3	28	1899	B, 10 inches	1,280	1,210	425	Gravel	Soft	do	1,400	1,500	0.50	Dom; irr.
99	W. F. Schee	1	3	28	1894	B, 7 inches	1,291				do	do				Irr.
100	Redlands Water Co.	1	3	35	1899	B, 10 inches	1,565				Hard	Centrifugal; steam			1.56	Irr.
101	Barton Land and Water Co.	1	3	28	1900	B, 10 inches	1,315	1,225	250							
102	Willis Miller	1	3	21	1898	B, 7 inches	1,290	1,208	123	SG	Hard	Wind	200	125	0.002	Dom.
103	S. A. Grover	1	3	21	1890	B, 7 inches	1,294				do	do				Dom; irr.
104	C. Cutting	1	3	21	1894	B, 7 inches	1,320	1,220	170		Soft	Cylinder pump; gas.	337	340		Dom; irr.
105	Myron Sherman	1	3	27	1892	B, 8 inches	1,331	1,221	145		do	Cylinder pump; electric.	450	300		Dom; irr.
106	J. S. Hale	1	3	21	1897	B, 11 inches	1,272	1,202	295	Gravel	Hard	Cylinder pump; gas.	600	1,300	0.48	Irr.
107	do	1	3	21	1890	B, 7 inches	1,265	1,201	105		do	Wind	159	200	0.002	Dom; irr.
108	do	1	3	17	1896	B, 10 inches	1,220	1,164	86		do	do	160	75	0.015	Irr.
109	C. A. Shaw	1	3	21	1893	B, 7 inches	1,267	1,217	96		Soft	do	138	87	0.005	Dom; irr.
110	Lewis Deck	1	3	21	1895	B, 7 inches	1,278	1,213	220	GC	do	Cylinder pump; gas.	363	678	0.15	Dom; irr.
110a	do	1	3	21	1895	B, 7 inches	1,278	1,213	150	GC	do				0.15	Dom; irr.
111	I. E. Shaw	1	3	21	1890	B, 7 inches	1,247	1,197	90		do	Hand	150	25		Dom.
112	Alise Van A. Lea	1	3	21	1898	B (2)	1,253		70 130	SLC	Hard	Cylinder pump; gas.	500	700		Not used.
113	A. Gregory	1	3	21	1890	B, 7 inches	1,245	1,194	100		Soft	Wind				Dom.

Wells in Redlands quadrangle—Continued.

No. of well.	Owner.	Location (T.R.S.).			Year completed.	Class of well.	Elevation of surface.	Elevation of water.	Depth of well.	Strata.	Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
		S.	W.				Feet.	Feet.	Feet.						Sec.-ft.	
114	Gladysta Land and Water Co.	1	3	20	1899	B, 11 inches	1,240					Cylinder pump; gas.				Irr.
115	Frank Hess	1	3	21	1897	B, 11 inches	1,243	1,188	163		Soft	Centrifugal; gas	$326	$800	0.24	Dom; irr.
116	C. S. Lombard	1	3	16	1897	B, 10 inches	1,246	1,182	180		Hard	Cylinder pump; gas.			0.30	Dom; irr.
117	S. Ronzone	1	3	16	1899	B, 9 inches	1,257	1,192	98	LSG	do	Wind	235	200	0.014	Dom; irr.
118	Thos. Blakeley	1	3	16		B	1,254				do	Electric				Irr.
119	Elza Boger	1	3	16	1899	D, 4 by 4 feet B, 9 inches	1,255	1,185	132	(a)						
120	M. R. Gay	1	3	17	1896	B, 11 inches (2)	1,220	1,170	105	SGC	Hard	Air compressor; electric.	200		0.22	Irr.
121	W. W. Story	1	3	16	1900	B, 10 inches	1,262	1,193	163	GC	do	Cylinder pump; gas.	400	1,500	0.50	Dom; irr.
122	John Dostal	1	3	15	1897	B, 10 inches	1,403	1,230	174	HpSG	Soft	Wind	348	140	Small.	Dom.
123	J. F. Boyd	1	3	16	1896	B, 10 inches (2)	1,290	1,180	100 110		do	Cylinder pump; gas.	500	900	0.20	Irr; dom.
124	Wm. Lindenberg	1	3	20	1893	B, 7 inches	1,220	1,180	93		Hard	Wind	140	150	0.009	Irr; dom.
125	H. S. Drew	1	3	19		B, 14 inches B, 10 inches	1,167	1,133	164 291		Soft	Cylinder pump; gas.	1,300	1,500	0.60	Irr; dom.
126	James Smith	1	3	19	1892	B, 7 inches	1,164	1,130	90		Hard	Hand	150	10		Dom.
127	Bryan estate	1	3	20	1900	B, 10 inches B, 8 inches	1,190	1,143	510 118		do	Centrifugal; gas			0.40	Irr.
128	A. M. Ham	1	3	30	1887	B, 7 inches B, 5 inches	1,155	1,120	150 300			Cylinder pump; gas.	1,500	900		Dom; irr.
129	P. H. Covington	2	3	10		B, 7 inches	1,440	1,392	58		Hard	Hand				Dom.
130	Clark & Brotherton	1	3	20	1900	B, 10 inches B, 8½ inches	1,195	1,162		LCG[a]						
131	J. J. Prendergast	1	3	29	1893	B, 10 inches	1,200	1,166	422		Hard	Cylinder pump; gas.	1,200	800	0.30	Irr; dom.
132	H. H. Cole	1	3	30	1888	B, 7 inches	1,140	1,108	82	LSG		Wind	140	180	Small.	Irr; dom.
133	H. S. Drew	1	3	19	1886	B, 7 inches	1,138		70		Hard	do	140	150	0.001	Dom.
134	C. M. Baxter	1	3	30	1899	B, 10 inches	1,147	1,116	100			Centrifugal; gas			0.60	Irr.
135	do	1	3	30	1892	B, 7 inches	1,147	1,113	80		Hard	Hand				Dom.
136	C. H. Lehmann	1	3	19	1891	B, 10 inches	1,129	1,103	458		Soft	Cylinder pump; gas.	1,300	900	0.40	Irr; dom.
137	A. E. Cole	1	3	30	1892	B, 7 inches	1,125	1,104	100	LSGC	Hard	Wind	160	100	0.005	Irr; dom.
138	A. McCrary	1	3	30	1891	B, 7 inches	1,120	1,093	40	CG	do	Hand	64			Dom.
139	H. R. Scott	1	3	19		B, 7 inches	1,120	1,108	503		do	Centrifugal; gas	1,000	1,000		Irr; dom.
140	do	1	3	19	1879	B, 6 inches	1,127	1,109	500		do					
141	E. H. Durnford	1	4	24	1894	B, 7 inches	1,109	1,093	500		Soft	Centrifugal; gas			0.60	Dom; irr.
142	James Birch	1	4	24	1890	B, 7 inches	1,096	1,087	300		do					Dom.
143	do	1	4	24		B, 7 inches	1,098	1,081	100							
144	D. W. Roach	1	4	24	1899	B, 7 inches	1,102	1,087	85	SG	Hard	Hand	130	24		Dom.
145	E. F. Van Leuven	1	4	25	1890	B, 7 inches	1,103	1,083	48		do	Wind			0.001	Dom.

146	W. H. Van Leuven	1	4	25		B, 7 inches	1,101	1,081	75		do	do				Dom; irr.
147	W. J. Doran	1	3	30	1900	B, 10 inches	1,106	1,086	100		do	do	200			Dom.
148	L. R. Van Leuven	1	3	30	1882	B, 7 inches	1,108	1,093	270		do	do	600	109	0.001	Dom; irr.
149		1	3	30		B, 7 inches	1,120				do	do				Dom; irr.
150	O. Taylor	1	3	32	1897	B, 7 inches	1,210		75		do	do		120	0.008	Dom; irr.
151	H. C. Hamanway	1	3	32		B, 7 inches	1,209				do	Hand				
152	G. J. Grant	1	3	32	1896	B, 7 inches (2)	1,206				do	Gas				Irr; dom.
153	S. L. Gregg	1	3	32		B, 7 inches	1,202				do	Wind				Dom.
154	H. C. Hamanway	1	3	32	1899	B, 10 inches	1,250	1,198	200		do	Cylinder pump; gas			0.32	Irr.
155	T. Morris	1	3	32	1890	B, 7 inches	1,260	1,195	125	LCG	do	Wind			0.002	Irr; dom.
156	S. V. Horton	1	3	32	1891	B, 7 inches	1,270	1,195	125	LCG		do	200	175	0.01	Irr; dom.
157	C. T. Covington	2	3	4	1891	B, 7 inches	1,455	1,415	65	SG	Hard	Hand	100	25		Dom.
158	Mrs. Van Leuven	1	4	25	1896	B, 7 inches	1,105	1,085	78		do	do	150	15		Dom.
159	J. H. Pierson	1	4	24	1884	B, 6 inches	1,104	1,108	605	CG	do	Centrifugal; gas	10,222	1,200	0.60	Dom; irr.
160	F. M. Strang	2	3	10	1897	D, 3 by 3 feet	1,500	1,423	79	SG	do	Hand	77	4		Dom.
161	Railroad School	2	3	10	1891	B, 7 inches	1,527	1,427	118	CG	do	do	180	25		Dom.
162	D. Mulvahill	2	3	10	1891	B, 7 inches	1,470	1,439	61	CG	do	do	115	22		Dom.
163	R. P. Lauretzen	2	3	10		B, 7 inches	1,550	1,474	106		do	do				Dom.
164		2	3	4		B, 7 inches	1,430				do	do				Dom.
165	— DeGarmo	2	3	8		B, 7 inches	1,575	1,485	164		do	Wind				Dom.
166	Smiley Bros	2	3	4		D, 7 by 7 feet	1,347	1,330	23		do	Centrifugal; gas			0.50	Irr.
277	L. F. Cram	1	3	3	1895	B, 12 inches	1,305	1,189	116	SCGR	Soft	Wind	1,000	100	Small.	Dom; irr.
278	C. C. Tyler	1	3	2	1900	D, 4 by 5 feet	1,305			SCGR						
279	John McBride	1	2	6	1900	D, 4 by 4 feet	1,650	1,636	65	SGB		Centrifugal; gas	500	400		Irr; dom.
280	do	1	2	6	1894	H, 4 by 6 feet	1,654	1,654	130	Granite	Hard	Tunnel, 130 ft., flows	250		0.02	Irr.
281	Cram Bros	1	3	2	1899	D, 4 by 4 feet	1,600	1,485	120	CG			300			
		N. W.														
282	E. Highland Orange Co.	1	3	35	1900	B, 12 inches; B, 10 inches	1,680	1,610	280; 140	SGR		Tunnel, flows	1,680		0.26	Dom; irr.
283	do	1	3	35	1900	D, 4 by 4 feet; B, 10 inches	1,680	1,666		SGR						
284	W. M. Bristol	1	3	34	1899	D, 5 by 5 feet	1,650	1,634	50	Gravel	Soft	Cylinder pump; gas		1,250	0.30	Irr.
285	Highland Domestic Water Co.	1	3	27	1899	D, 7 by 9 feet	1,440	1,411	65	GB		2 cylinder pumps; 2 gas engines.		[b]1,500	1.10	Dom.
286	Highland Well Co	1	3	28	1899	D, 8 by 5 feet	1,431	1,415	46			Cylinder pump; gas			0.68	Irr.
		S. W.														
287	J. C. Weeks	1	3	3	1900	D, 4 by 4 feet; B, 12 inches	1,295	1,181	([a])		Hard					
288	H. S. Stroven	1	3	3	1898	B, 10 inches	1,258	1,173	165		Soft	Cylinder pump; gas	400	1,160	0.40	Irr; dom.
289	N. Sutherland	1	3	4	1898	Dug; B, 12 inches	1,227	1,160	78		Hard					Not used.
290	Pattee & Nye	1	3	5	1900	D, 6 by 8 feet; B, 10 inches	1,200	1,150	50; 100			Rotary pump; steam			0.60	Irr.
291	G. J. Fowler	1	3	5	1899	D, 5 feet	1,180	1,127	55	SCG	Soft	Hand	50	17		Dom.
292	R. F. Cunningham	1	3	5	1890	D, 6 feet	1,160	1,120	43	Gravel	do	Centrifugal; steam	150	1,450	0.80	Irr.
293	do	1	3	5	1899	B, 7 inches	1,147	1,108	36		do	Hand	160	15		Dom.
		N. W.														
294	do	1	3	31	1900	D, 5 by 5 feet; B, 10 inches	1,260	1,226	185; 90	CG		Steam			1.04	Irr.

[a] Unfinished.

[b] Two engines.

Wells in Redlands quadrangle—Continued.

No. of well.	Owner.	Location (T.R.S.).	Year completed.	Class of well.	Elevation of surface.	Elevation of water.	Depth of well.	Strata.	Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
		S. W.			*Feet.*	*Feet.*	*Feet.*						*Sec.-ft.*	
295	Redlands Water Co.	1 3 35	1899	B, 10 inches	1,568				Hard					
296	C. K. Matteson	1 3 7	1892	B, 10 inches	1,107	1,083	47	CG	Soft	Centrifugal; steam	$500		0.20	Irr.
297	do	1 3 7	1884	Dug	1,103	1,080	25	SGC	do	Hand	30	$4		Dom.
298	do	1 3 7	1894	B, 10 inches	1,103	1,083	44	SG	do	Centrifugal; gas	175	510	0.60	Irr.
299	Geo. Gustave	1 3 7	1900	D, 4 by 6 feet	1,101	1,082	25	SGR	do	do	50		0.30	Irr; dom.
300	do	1 3 7		D, 3 by 4 feet	1,103	1,085	19	SGB	do					
301	Mrs. H. Taylor	1 3 7		D, 3 feet	1,102	1,080	25	Gravel		Centrifugal; steam				Irr.
302	C. Wiltshire	1 3 6	1895	Dr, 2 inches	1,102	1,080	27		Soft	Hand		25		Dom.
303	Mrs. H. Taylor	1 3 7	1891	B, 3 inches	1,101		235		do	do	300		3.00	Dom; irr.
304	W. F. Somers	1 3 7	1900	B, 10 inches	1,101	1,081	(a)	SGCB						
305	Mrs. Golden	1 4 12	1900	B, 10 inches	1,099	1,099		SGC		Artesian				Irr.
306	do	1 4 12	1898	B, 8 inches	1,102	1,102	744		Soft	do	1,600		[b]1.10	Dom; irr.
307	W. F. Somers	1 3 7	1895	Dug	1,098	1,080	20		do	Hand	20		7.00	Dom.
308	do	1 3 7	1899	D, 3 by 3 feet	1,097	1,079	20		do	do	20		4.00	St.
309	John Kaus	1 3 7	1899	B, 8 inches	1,103	1,085	20			Steam	40			Dom.
310	F. P. Sargent	1 4 13	1894	Dr, 2 inches	1,096	1,084	24	Sand	Hard	Hand	15	10		Dom.
311	S. E. Fitzhugh	1 4 12	1888	B, 3 inches	1,080	1,073	234	SGC	Soft	do	500	6		Dom.
312	do	1 4 12	1885	B, 7 inches	1,081	1,064	20		Hard	do	35	6		Dom.
313	W. Borne	1 3 7		D, 3½ by 3½ feet	1,103					do				Dom.
314	Geo. Covalt	1 3 7	1899	B, 7 inches	1,104	1,079	30		Hard	do		4		Dom.
315	W. F. Somers	1 4 1		B, 3 inches	1,099	1,095	283		Soft	do				Dom.
316	W. K. Bledsoe	1 4 1		D, 4½ feet	1,103	1,086	21	SG	Hard	do	25	3		Dom.
317	T. J. West	1 4 1	1900	D, 5 feet	1,093	1,090	20	SG	Soft	Centrifugal; steam	400	820	1.30	Irr.
318	S. Van Leuven	1 3 6	1883	B, 3 inches	1,104	1,105	309		do	Wind				Irr; dom.
319	Ed. Dailey	1 3 6	1890	B, 3 inches	1,102	1,091	325		do	Hand				Dom.
320	do	1 3 6	1890	B, 3 inches	1,106	1,105	320		do					Not used.
321	do	1 3 6	1885	B, 3 inches	1,103	1,093	350		do	Hand				Dom.
322	W. A. Brouse	1 3 6	1899	Dug	1,104	1,084	22	SG	do	do	25	5		Dom.
323	do	1 3 6	1884	D, 5 feet	1,104	1,084	26	SG	do	Centrifugal; steam	150	630	0.50	Irr.
324	do	1 3 6	1893	D, 5 feet	1,106	1,086	25		do	do	150	620	0.50	Irr.
325	Herman Smith	1 3 6	1899	D, 4 by 4 feet	1,109	1,084	27	SG	do	Hand	100	12		Dom.
326	J. Friedmann	1 3 6	1885	D, 6 feet	1,107	1,090	22	SG	do	Centrifugal; steam	130	485	1.00	Irr; dom.
327	J. Dunlap	1 4 1		B, 3 inches	1,102	1,102	185		Hard	Artesian			0.18	Dom.
328	H. C. Keller	1 4 1	1880	B, 2 inches	1,104	1,104	169		Soft	do			0.02	Dom.
329	A. Roberts	1 3 6	1892	B, 3 inches	1,105	1,105	231		do	do	426		0.005	Dom.
330	Warm Creek School	1 3 6	1885	B, 2 inches	1,106	1,101	150			Hand	175			Dom.
331	W. L. McKenzie	1 4 1	1875	B, 2 inches	1,105	1,105	320		Soft	Artesian			0.01	Irr; dom
		N. W.												
332	Wm. Shay	1 3 31	1890	B, 3 inches	1,103	1,103	150		do	do	300		0.06	Dom.

		S. W.														
333	Wm. Clyde	1	3	6	1889	B, 2 inches	1,106	1,106	146		Soft	Artesian	150		0.08	Irr; dom.
334	Riverside Water Co.	1	4	1	1898	B, 10 inches	1,086		648	CGS	Hard	do				Irr.
335	do	1	4	1	1898	B, 10 inches	1,088		590	SGC	do	do	1,100		1.20	Irr.
336	do	1	4	1	1898	Bored	1,085		384	SCG	do	do				Irr.
337	do	1	4	1		Bored	1,084	1,084	440		do	do				Irr.
338	Redlands Dom. W. Co	1	3	35	1899	B, 10 inches (2)	1,640	1,550	243 400	CSG	do	Centrifugal; electric	650		0.80	Dom.
		N. W.														
339	Thomas Shay	1	3	31	1888	B, 7 inches	1,108	1,089	20	SGC	Soft	Hand	30	5		Dom.
340	do	1	3	31	1895	D, 4 by 4 feet B, 8 inches	1,098		80		Hard	Cylinder pump; gas.	300	1,680	0.50	Irr.
		S. W.														
341	R. T. Clyde	1	3	6	1880	B, 2 inches	1,105	1,105	133		Soft	Artesian	[a]100			Dom; irr.
342	F. L. Talmadge	1	3	6	1880	B, 2 inches	1,106	1,106	135		do	Hand	100	5		Dom.
343	Talmadge & Haws	1	3	6	1897	B, 10 inches	1,140	1,132	425	SCBG	do	Centrifugal; gas	850	986	2.00	Irr.
344	Mrs. Haws	1	3	6	1898	B, 2 inches	1,125	1,125	100		do	Hand	75	8		Dom.
		N. W.														
345	John D. Clark	1	3	31	1899	B, 3 inches	1,130	1,130	125	LCSG	Hard	Artesian	120		0.02	Dom; irr.
346	do	1	3	31	1892	B, 3 inches	1,132	1,132	50	CG	do	do	45			Dom; irr.
347	D. R. Seely	1	3	33	1890	B, 3 inches	1,250	1,176	124		Soft	Wind			0.005	Dom.
348	do	1	3	33	1899	B, 12 inches	1,285	1,110	195			Cylinder pump; gas.				Irr.
		S. W.														
349	W. D. Stevens	1	3	5	1894	D, 8 feet B, 10 inches	1,180	1,180	40 60		Hard	Centrifugal; gas		815	0.60	Irr; dom.
350	Jane C. Goodman	1	3	6	1894	B, 3 inches	1,140	1,128	284		do	Wind	625	108	0.001	Irr; dom.
351	Jas. Roddick	1	3	5	1898	D, 4 inches	1,143	1,114	30		do	Centrifugal; gas		250	0.20	Irr; dom.
352	Saml. Roddick	1	3	6	1899	Dr, 1¼ inches	1,139	1,117	27		do	Hand	7	10		Dom.
353	W. F. Talmadge	1	3	6	1885	B, 7 inches	1,148	1,132	30		do	Wind		80	0.001	Dom; irr.
354	do	1	3	6	1891	B, 3 inches	1,146	1,131	41		do	Hand		6		Dom.
355	A. Downey	1	3	6	1899	Dr, 1¼ inches	1,143	1,131	21		Soft	do	4	3		Dom.
356	F. A. Haws	1	3	6	1899	Dr, 1¼ inches	1,130	1,120	26		Hard	do	5	5		Dom.
357	E. S. Haws	1	3	6	1899	Dr, 1¼ inches	1,130	1,120	20		do	do	5	5		Dom.
358	Mrs. M. C. Haws	1	3	6	1895	B, 3 inches	1,125	1,125	125		Soft	Artesian	250			Dom.
		N. W.														
359	Walter Shay	1	3	31		B, 7 inches	1,110				Hard	Hand				Dom.
360	Kohl Bros	1	3	32	1890	B, 6 inches	1,147	1,129	60		do	Wind			0.001	Dom.
361	H. D. Rabel	1	3	31	1896	B, 2 inches	1,140	1,140	68		Soft	Artesian	40			Dom.
362	do	1	3	31	1898	B, 3 inches	1,142	1,142	86		do	do	70		0.01	Dom.
363	do	1	3	31	1898	B, 3 inches	1,139	1,139	44		do	do	30		0.25	Dom.
364	do	1	3	31		B, 3 inches	1,137	1,137	72		do	do	70		0.005	Dom.
365	Geo. Miller	1	3	32	1898	B, 6¼ inches	1,130	1,043	92		do	Wind	700	100		Dom.
366	D. J. Carpenter	1	4	24	1900	D, 6 by 9 feet	1,470	1,447	25	CS	Alk					
367	D. J. Carpenter & Co.	1	4	24		B, 7 inches	1,475	1,475	71	SG	do				0.06	Irr.
368	do	1	4	24		B, 7 inches	1,474	1,474	123	SG	do				0.10	Irr.
369	do	1	4	24		B, 7 inches	1,474	1,474	193	SG	do				0.08	Irr.
370	do	1	4	24		B, 7 inches	1,476	1,476	184	SG	do	Centrifugal; gas		1,100	0.14	Irr.
371	do	1	4	24		B, 7 inches	1,473	1,473		SG	do				0.10	Irr.
372	do	1	4	24		B, 7 inches	1,473	1,473	127	SG	do				0.10	Irr.
373	do	1	4	24		B, 7 inches	1,473	1,473	167	SG	do				0.06	Irr.
374	W. J. Linville	1	3	30	1899	B, 10 inches	1,270	1,140	368		Hard	Cylinder pump; gas.		3,000	0.36	Irr.

[a] Not completed.

[b] December, 1898.

Wells in Redlands quadrangle—Continued.

No. of well.	Owner.	Location (T. R. S.).	Year completed.	Class of well.	Elevation of surface.	Elevation of water.	Depth of well.	Strata.	Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
		S. W.			*Feet.*	*Feet.*	*Feet.*						*Sec.-ft.*	
375	Mrs. R. L. Burcham	1 3 31	1899	B, 12 inches	1,224	1,154	460		Soft	Cylinder pump; gas.	$1,200	$2,250	0.70	Irr.
376	E. K. Henderson	1 3 30	1899	B, 8 inches	1,233	1,133	134		do	Wind	150			Dom.
377	Jas. McCafferty	1 3 31	1896	B, 7 inches	1,225		80-100		do	Cylinder pump; gas.		2,500	0.40	Irr; dom.
378	J. D. Clark	1 3 31	1897	B, 11 inches	1,170		106	LCB	do	do			0.40	Irr.
379	P. W. Gray	1 3 31	1893	B, 7 inches	1,170	1,120	139		Hard	Wind			0.08	Dom; irr.
380		1 3 30	1900	B, 7 inches	1,310		320	SCGB						
381	John Lin Foster	1 3 32	1894	B, 10 inches	1,220		95		Soft	Wind	600	(a)	0.008	Dom; irr.
382	P. H. Gleason	1 3 32	1900	D, 4 by 4 feet	1,250	1,175	78		do	do			0.002	Dom; irr.
383	E. L. Cumbl	1 3 32	1897	D, 4 by 4 feet	1,128	1,091	38	CSB	Hard	Hand	50			Dom.
384	A. C. Pierce	1 3 32	1898	D, 4 by 4 feet	1,210	1,150	62	LSGB	Soft	Wind	120	140	0.005	Dom; irr.
385	Kohl Bros	1 3 32	1898	B, 10 inches	1,148	1,136	300	SGB	do	Centrifugal; gas	600	700	1.60	Dom; irr.
		S. W.												
386	State of California Hospital for Insane.	1 3 5		B, 10 inches	1,110	1,078	85		Hard	Centrifugal; steam			1.60	Irr.
		N. W.												
387	Geo. Fowler	1 3 32	1888	D, 3 by 3 feet	1,165	1,137	29	CG	Soft	Hand				Dom.
		S. W.												
388	C. D. Fowler	1 3 5	1895	D, 4 feet	1,168	1,135	34	CSGB	Hard	do				Dom.
		N. W.												
389	J. Bagwell	1 3 32	1900	D, 4 by 4 feet; B, 12 inches	1,230	1,117	153		do	Cylinder pump; gas.			0.20	Irr.
390	A. A. Boyd	1 3 32	1895	Dug; B, 7 inches	1,290	1,138	202		do	do			0.22	Irr; dom.
391	Gage Canal Co.	1 4 13	1891	B, 10 inches	1,058	1,058	168		do	Artesian			b 4.306	Irr.
392	do	1 4 13	1891	B, 10 inches	1,059	1,059	166		do	do			b 1.521	Irr.
393	do	1 4 13	1891	B, 10 inches	1,061	1,061	152		do	do			b 1.521	Irr.
394	do	1 4 13	1891	B, 10 inches	1,063	1,063	123		do	do			b 1.712	Irr.
395	do	1 4 13	1891	B, 10 inches	1,066	1,066	125		do	do			b 0.594	Irr.
396	do	1 3 18	1887	B, 10 inches	1,062	1,062	144		do	do			b 2.131	Irr.
397	do	1 3 18	1887	B, 10½ inches	1,064	1,064	140		do	do			b 1.011	Irr.
398	do	1 3 18	1888	B, 10 inches	1,075	1,075	138		do	do			b 0.605	Irr.
399	do	1 3 18	1888	B, 10 inches	1,075	1,075	106		do	do			b 0.188	Irr.
400	do	1 3 18	1888	B, 10 inches	1,074	1,074	130		do	do			b 0.563	Irr.
401	do	1 3 18	1888	B, 10 inches	1,071	1,071	146		do	do			b 2.212	Irr.
402	do	1 3 18	1888	B, 10 inches	1,065	1,065	116		do	do			b 3.176	Irr.
403	do	1 3 18	1888	B, 10 inches	1,064	1,064	134		do	do			b 1.424	Irr.
404	do	1 3 18	1888	B, 10 inches	1,061	1,061	116		do	do			b 0.594	Irr.
405	do	1 4 13	1887	B, 10 inches	1,057	1,057	147		do	do			b 2.254	Irr.
406	do	1 4 13	1887	B, 10 inches	1,058	1,058	122		do	do			b 1.026	Irr.
407	do	1 4 13	1892	B, 10 inches	1,059	1,059	115		do	do			b 0.484	Irr.

408	do	1	4	13	1892	B, 10½ inches	1,053	1,053	160		do	do			[a] 8.105	Irr.
409	do	1	3	18	1886	B, 7 inches	1,077		127		do	[d]			[c] 0.286	Irr.
410	do	1	3	18	1886	B, 7 inches	1,076		127		do	[d]			[c] 0.302	Irr.
411	do	1	3	18	1886	B, 7 inches	1,077		125		do	[d]			[c] 0.270	Irr.
412	do	1	3	18	1886	B, 7 inches	1,077		125		do	[d]			[c] 0.416	Irr.

[a] Included in cost of well.
[b] Flow of wells Nos. 391 to 412 is given for October, 1892.
[c] December, 1896.
[d] Wells 409 to 412 are pumped by 15-horsepower gas engine and centrifugal pump, raising 2 second-feet of water. These were artesian wells when sunk.

Wells in San Bernardino quadrangle.

No. of well.	Owner of well.	Location (T.R.S.).			Year completed.	Class of well.	Elevation of surface.	Elevation of water.	Depth of well.	Strata.	Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
		S.	W.				Feet.	Feet.	Feet.						Sec.-ft.	
1	Riverside Water Co.	1	4	27	1887	11-inch pipe	1,014	1,014	115		Hard	Artesian			[a] 0.329	Dom.
2	do	1	4	27		11-inch pipe	1,015	1,015	118		do	do			[b] 0.284	Dom.
3	do	1	4	27		11-inch pipe	1,015	1,015	118		do	do			[b] 0.117	Dom.
4	do	1	4	27		11-inch pipe	1,016	1,016	111		do	do			[b] 0.153	Dom.
5	do	1	4	27		11-inch pipe	1,014	1,014	112		do	do			[b] 0.117	Dom.
6	do	1	4	27		11-inch pipe	1,016	1,016	120		do	do			[b] 0.150	Dom.
7	do	1	4	27	1888	7-inch pipe	1,013	1,013	128	BCS	do	do	$400		[b] 0.150	Dom.
8	do	1	4	27	1888	9-inch pipe	1,016	1,016	125	BCS	do	do	525		[b] 0.096	Dom.
9	do	1	4	27	1888	9.5-inch pipe	1,018	1,018	123	BCS	do	do	500			Dom.
10	do	1	4	27	1888	9-inch pipe	1,017	1,017	127	BCS	do	do	550			Dom.
11	do	1	4	27	1888	9-inch pipe	1,021	1,021	201	BCS	do	do	800		[b] 0.125	Dom.
12	do	1	4	27		9-inch pipe	1,020	1,020	141	BCSG	do	do	650			Dom.
13	do	1	4	27	1889	9-inch pipe	1,015	1,015	127	CSGB	do	do	525			Dom.
14	do	1	4	27	1889	9-inch pipe	1,014	1,014	125	CSGB	do	do	550		[b] 0.068	Dom.
15	do	1	4	22	1889	11-inch pipe	964	964	86	CSGB	do	do	480		[c] 0.442	Irr.
16	do	1	4	22	1889	9-inch pipe	981	981	123	CSBG	do	do			[c] 0.083	Irr.
17	do	1	4	22	1889	9-inch pipe	955	955	81	SCB	do	do			[c] 0.900	Irr.
18	do	1	4	22	1889	9-inch pipe	955	955	92	SGCB	do	do			[c] 0.361	Irr.
19	do	1	4	16	1889	9-inch pipe	972	972	225	SCGB	do	do			[b] 0.158	Irr.
20	do	1	4	16	1889	7-inch pipe	978	978	75	CSB	[d]	[d]			[d]	
21	do	1	4	16	1891	7-inch pipe	971	971	175	SCB	[d]	[d]			[d]	
22	do	1	4	16	1889	9-inch pipe	973	973	55	CSB	Hard	Artesian			0.173	Irr.
23	do	1	4	16	1889	9-inch pipe	974	974	121	SBCS	do	do			0.355	Irr.
24	do	1	4	22	1889	7-inch pipe	989	989	192	CSGB	do	do			[c] 0.175	Irr.
25	do	1	4	22	1889	9-inch pipe	968	968	81	SCGB	do	do			[c] 0.207	Irr.
26	do	1	4	22	1889	9-inch pipe	967	967	83	SCB	do	do			[c] 0.361	Irr.
27	do	1	4	22	1889	9-inch pipe	981	981	103	SCGB	do	do			[c] 0.952	Irr.

[a] 1890. [b] 1891. [c] 1896. [d] Well filled and covered with sand from flood and lost.

Wells in San Bernardino quadrangle—Continued.

No. of well.	Owner of well.	Location (T.R.S.).			Year completed.	Class of well.	Elevation of surface.	Elevation of water.	Depth of well.	Strata.	Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
		S.	W.				Feet.	Feet.	Feet.						Sec.-ft.	
28	Riverside Water Co	1	4	22	1889	9-inch pipe	970	970	83	SCB	Hard	Artesian			[a]0.278	Irr.
29	do	1	4	22	1889	9-inch pipe	979	979	101	SCGB	do	do			[a]0.640	Irr.
30	do	1	4	22	1890	9-inch pipe	978	978	97	SCGB	do	do			[a]1.417	Irr.
31	do	1	4	22	1890	9-inch pipe	980	980	165	SCGB	do	do			[a]0.569	Irr.
32	do	1	4	22	1890	9-inch pipe	979	979	165	SCBG	do	do			[a]0.616	Irr.
33	do	1	4	27	1891	9.5-inch pipe	1,012	1,012	330	SGCR	do	do			[b]8.28	Dom.
34	do	1	4	27	1891	9.5-inch pipe	1,012	1,012	326	CSGR	do	do				Dom.
35	do	1	4	22		9.5-inch pipe	977	977	82	CSGB	do	do	$255		[c]0.860	Irr.
37	do	1	4	27		9.5-inch pipe	1,012	1,012	249	CSGR	do	do				Dom.
38	do	1	4	1	1892	7-inch pipe	1,083	1,083	187	SGC	do	do	662		[d]0.027	Irr.
39	do	1	4	1	1893	9.5-inch pipe	1,083	1,083	396	SBCRG	do	do			[d]0.714	Irr.
42	do	1	4	27	1893	9.5-inch pipe	1,011	1,011	344	CSB	do	do				Dom.
43	do	1	4	1	1894	9.5-inch pipe	1,086	1,086	420	SGC	do	do	630		[a]1.452	Irr.
44	do	1	4	22	1896	9-inch pipe	979	979	133		do	do	250		[a]0.971	Irr.
45	do	1	4	22	1896	9-inch pipe	979	979	173	SB	do	do	420			Irr.
47	do	1	4	3	1898	9-inch pipe	1,025	1,025	168	SB	do	do	500			Irr.
51	do	1	4	22		8-inch pipe	954	954	78		do	do				Irr.
52	do	1	4	22		8-inch pipe	955	955	94	SCG	do	do				Irr.
53	do	1	4	22	1898	8-inch pipe	956	956	68	SCG	do	do				Irr.
54	do	1	4	22	1898	8-inch pipe	957	957	68		do	do				Irr.
55	do	1	4	22	1898	7-inch pipe	958	958	92		do	do				Irr.
56	do	1	4	22	1898	7-inch pipe	959	959	75		do	do				Irr.
57	do	1	4	22	1898	8-inch pipe	960	960	92	CS	do	do	128			Irr.
58	do	1	4	22	1898	7-inch pipe	960	960	87	CBGS	do	do	157		[f]0.456	Irr.
59	do	1	4	22	1898	8-inch pipe	961	961	85	SCB	do	do	138		[f]0.622	Irr.
60	do	1	4	22	1898	7-inch pipe	961	961	93	SCB	do	do	173		[f]0.456	Irr.
61	do	1	4	22		8-inch pipe	952	952			do	do				Irr.
62	do	1	4	15	1898	8-inch pipe	985	985	183	SCG	do	do			[f]0.34	Irr.
65	do	1	4	2	1900	10-inch pipe	1,040	1,040	540	GCS	Soft	do			2.89	Irr.
66	do	1	4	2	1900	10-inch pipe	1,035	1,035	580	GCSR	Hard	do			2.606	Irr.
67	Wm. Roach	2	4	6	1889	7-inch pipe	904	852	130		Soft	10 wind	200	$160	0.015	Irr; dom.
68	do	2	4	6	1875	7-inch pipe	905	852	70		do	12 wind	105	130	0.006	Irr.
69	Mrs. Douglas	2	4	6	1893	7-inch pipe	895	835	112		do	Wind			0.015	Irr; dom.
70	Louise Peña	2	5	12	1888	D, 3 by 4 feet	835	815	22		Hard	do		110	Small.	Dom.
71	P. Evans	2	5	12	1900	10-inch pipe	840	840	400			Artesian			1.000	Irr.
72	P. Baca	2	5	12	1899	D, 3 by 3 feet	852	832	22		Hard	Hand	20		Small.	Dom.
73	W. L. Zader	1	4	29	1894	D, 3 feet dia	980	930	52		do	8 wind	40	95	do	Dom.
74	D. Jones	1	4	29	1888	D, 3 feet dia	980		70			Wind	100	200		
75	T. J. Smith	1	4	30	1890	D, 3 feet dia	974		38			do				
76	Mrs. B. R. Atkins	1	4	30	1897	D, 3 feet dia	980	938	59		Hard	9 wind		500	Small.	Dom.

77	.....	1	4	30	.....	D, 3 by 3 feet	886	871	17	.....	.....	Hand	.....	.....	.....	Dom.
78	.....	1	4	30	.....	D, 3 by 3 feet	875	871	6	.....	.....	do	.....	.....	.....	Dom.
79	Thos. McGraw	1	5	35	1895	D, 4 by 4 feet	875	837	39	SCG	Soft	do	70	14	Small.	Dom.
80	Henry Carson	2	5	10	1900	D, 3 feet dia.	831	784	49	SGR	do	.....	40	.....	.....	Dom.
81	Dan. Baker	2	5	10	1885	6-inch pipe	826	786	60	.....	do	Hand	.....	20	.....	Dom.
82	Mrs. Burgess	1	5	34	.....	D, 4 by 4 feet	988	838	150	.....	.....	Wind	.....	.....	.....	Not used.
83	T. Pulley	2	5	10	(g)	B, 20 inches	881	808	89	.....	.....	.....	.....	.....	.....	
84	Mrs. L. M. Henry	2	5	10	1898	6-inch pipe	895	787	128	.....	Hard	Wind	.....	.....	.....	Irr; dom.
85	T. Pulley	2	5	10	1898	D, 3 feet dia	850	780	72	.....	do	do	50	120	.....	Irr; dom.
86	John Miller	2	5	10	1900	D, 3 feet dia	866	800	69	.....	Soft	do	40	.....	.....	Dom.
87	Ed. Bridson	2	5	15	1898	7-inch pipe	840	780	100	GS	Hard	10 wind	150	150	.....	Dom; st.
88	J. Rogerson	2	5	15	.....	D, 4 by 4 feet	830	794	37	.....	.....	Hand	.....	.....	.....	Dom.
89	Mrs. A. Parks	2	5	15	.....	7-inch pipe	810	798	28	.....	Hard	Wind	.....	.....	.....	Dom; st.
90	H. C. Parks	2	5	9	1887	D, 3 feet dia	850	784	75	.....	do	do	325	180	.....	Dom; st.
91	Scott La Rue	2	5	9	1900	D, 3 feet dia	845	742	107	SG	.....	do	100	285	.....	Dom; st.
92	Emuel Spooner	2	5	8	1896	D, 4 by 4 feet	850	750	105	SG	Hard	do	115	.....	.....	Dom; st.
93	do	2	5	8	1900	D, 4 by 4 feet	850	750	107	SG	.....	.....	125	.....	.....	
94	W. J. Thomas	2	5	7	1900	D, 4½ by 4 feet	847	817	35	SGB	Soft	.....	70	.....	.....	Dom.
95	E. Thomas	2	5	7	1899	D, 3 by 3 feet	850	814	41	SG	do	Wind	75	150	.....	Irr.
96	do	2	5	7	1894	D, 3 by 3 feet	841	817	26	.....	do	Hand	40	.....	.....	Dom.
97	Mrs. H. M. Thurber	2	6	12	1896	D, 5 feet dia	800	782	28	.....	do	Wind	.....	.....	.....	Irr; dom.
98	F. D. Lewis	2	6	13	.....	D, 4 by 4 feet	795	775	40	.....	do	10 wind	.....	.....	.....	Dom.
99	.....	2	6	12	.....	D, 4 by 4 feet	789	770	31	.....	.....	do	.....	.....	.....	Dom.
100	John Parkhurst	2	6	12	1898	D, 6 feet dia	818	807	13.5	SR	Soft	12 wind	100	135	.....	Dom.
101	J. R. Johnston	2	5	6	.....	Pipe line	.....	.....	.....	.....	.....	.....	.....	.....	.....	Dom.; st.
102	I. McBride	2	6	12	1892	D, 3.5 by 3.5 feet	813	787	55	SR	Soft	8 wind	80	100	Small.	Dom.
103	Milo Gilbert	1	4	24	1900	7-inch pipe	1,004	864	220	.....	.....	12 wind	.....	.....	.....	
104	Riverside Trust Co	1	4	24	1898	10-inch pipe	1,077	1,077	506	CSGR	Hard	Artesian	.....	.....	1.600	Irr.
105	do	1	4	24	1898	10-inch pipe	1,071	1,071	531	CSG	do	do	.....	.....	1.200	Irr.
106	do	1	4	24	1898	10-inch pipe	1,065	1,065	517	CSGR	do	do	.....	.....	1.400	Irr.
107	do	1	4	23	1899	10-inch pipe	1,045	1,045	675	CSGR	do	do	.....	.....	1.500	Irr.
108	do	1	4	24	1899	10-inch pipe	1,076	1,076	568	CSGR	do	do	.....	.....	2.040	Irr.
109	do	1	4	26	1899	10-inch pipe	1,019	1,019	554	CSGR	do	do	.....	.....	0.400	Irr.
110	do	1	4	13	1899	10-inch pipe	1,052	1,052	580	.....	do	do	.....	.....	.....	Irr.
111	do	1	4	13	1899	10-inch pipe	1,061	1,061	537	CSGR	do	do	.....	.....	2.600	Irr.
112	do	1	4	13	1899	10-inch pipe	1,066	1,066	577	CSGR	do	do	.....	.....	1.200	Irr.
113	do	1	4	13	1899	10-inch pipe	1,069	1,069	505	CSGR	do	do	.....	.....	1.040	Irr.
114	do	1	4	13	1900	10-inch pipe	1,079	1,079	478	CSGR	do	do	.....	.....	3.000	Irr.
115	Gage Canal Co	1	4	26	1891	10-inch pipe	1,033	1,033	656	.....	do	do	.....	.....	0.089	Irr.
116	do	1	4	26	1891	10-inch pipe	1,034	1,034	534	.....	do	do	.....	.....	0.956	Irr.
117	do	1	4	26	1891	10-inch pipe	1,034	1,034	582	.....	do	do	.....	.....	0.770	Irr.
118	do	1	4	26	1891	10-inch pipe	1,034	1,034	482	.....	do	do	.....	.....	1.026	Irr.
119	do	1	4	26	1891	10½-inch pipe	1,034	1,034	320	.....	do	do	.....	.....	0.064	Irr.
120	do	1	4	26	1891	10-inch pipe	1,034	1,034	784	.....	do	do	.....	.....	1.089	Irr.
121	do	1	4	23	1888	10½-inch pipe	1,036	1,036	196	.....	do	do	.....	.....	0.550	Irr.
122	do	1	4	23	1888	10½-inch pipe	1,036	1,036	190	.....	do	do	.....	.....	0.979	Irr.
123	do	1	4	23	1889	10-inch pipe	1,036	1,036	142	.....	do	do	.....	.....	0.188	Irr.
124	do	1	4	23	1889	10½-inch pipe	1,036	1,036	148	.....	do	do	.....	.....	0.121	Irr.

[a] 1896. [b] 1891. [c] 1892. [d] 1900. [e] 1894. [f] 1898. [g] Not finished.

NOTE.—No. 48 is No. 335 of Redlands quadrangle; no record for Nos. 36, 40, 41, and 49; Nos. 50, 63, and 64 are Nos. 334, 336, and 337, respectively, of Redlands quadrangle; No. 46 is also in Redlands quadrangle.

Wells in San Bernardino quadrangle—Continued.

No. of well.	Owner of well.	Location (T.R.S.).			Year completed.	Class of well.	Elevation of surface.	Elevation of water.	Depth of well.	Strata.	Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
		S.	W.				Feet.	Feet.	Feet.						Sec.-ft.	
125	Gage Canal Co	1	4	24	1886	7-inch pipe	1,037	1,037	141		Hard	Artesian			2.330	Irr.
126	do	1	4	13	1886	7-inch pipe	1,037	1,037	181		do	do			1.928	Irr.
127	do	1	4	13	1891	10-inch pipe	1,037	1,037	426		do	do			5.901	Irr.
128	do	1	4	13	1891	10-inch pipe	1,037	1,037	472		do	do			1.874	Irr.
129	do	1	4	13	1891	10-inch pipe	1,048	1,048	518		do	do			1.874	Irr.
130	do	1	4	13	1891	10-inch pipe	1,049	1,049	338		do	do			1.264	Irr.
131	do	1	4	13	1891	10-inch pipe	1,049	1,049	380		do	do			0.770	Irr.
132	do	1	4	13	1891	10-inch pipe	1,049	1,049	396		do	do			1.424	Irr.
133	do	1	4	13	1891	10-inch pipe	1,052	1,052	198		do	do			5.314	Irr.
134	do	1	4	13	1891	10-inch pipe	1,057	1,057	124		do	do			1.299	Irr.
135	do	1	4	13	1891	10-inch pipe	1,055	1,055	116		do	do			2.746	Irr.
136	do	1	4	13	1891	10-inch pipe	1,057	1,057	134		do	do			5.663	Irr.
155	do	1	4	13	1892	10-inch pipe	1,051	1,051	198		do	do			8.299	Irr.
156	do	1	4	13	1892	10-inch pipe	1,046	1,046	192		do	do			8.315	Irr.
157	do	1	4	13	1892	10½-inch pipe	1,044	1,044	390		do	do			4.835	Irr.
158	do	1	4	13	1892	10-inch pipe	1,042	1,042	224		do	do			5.697	Irr.
159	do	1	4	13	1885	7-inch pipe	1,045		123		(a)	(a)			1.923	Irr.
160	do	1	4	13	1885	7-inch pipe	1,045		133		(a)	(a)			0.473	Irr.
161	do	1	4	13	1885	7-inch pipe	1,045		133		(a)	(a)			3.015	Irr.
162	do	1	4	13	1885	5-inch pipe	1,048		139		(a)	(a)			8.217	Irr.
163	do	1	4	13	1885	7-inch pipe	1,048		211		(a)	(a)			4.641	Irr.
164	do	1	4	13	1885	7-inch pipe	1,046		100		(a)	(a)			0.579	Irr.
169	do	1	4	13	1890	10-inch pipe	1,067	1,067	300			Artesian			5.901	Irr.
170	Riverside Trust Co	1	4	23	1900	10-inch pipe	1,011	1,011	582			do			6.181	Irr.
171	Bloomington Land Co.	1	5	22	1900	12-inch pipe	1,100	858	454	SGCR		do	$1,200			Not used.
172	D. Johnson	1	4	8		8-inch pipe	1,095	1,081	283		Soft		600			Not used.
173	Fox, Archibald & Lantz.	1	4	8			1,089					Centrifugal; 10 gas			0.414	Irr.
174	Jas. Lamb	1	4	8	1894	8-inch pipe	1,097	1,083	102		Soft	do	200	$1,800	0.400	Irr.
175	Jas. Barnhill	1	4	8		8-inch pipe	1,097					Centrifugal; 15 electric.			0.800	Irr.
176	City of Colton	1	4	8	1899	10-inch pipe	1,087	1,070	490		Soft	Centrifugal; electric			0.834	Irr; dom.
177	do	1	4	8	1899	8-inch pipe	1,084	1,068	90		do	do			0.200	Irr; dom.
178	G. W. Curtis	1	4	24	1895	7-inch pipe	1,088	1,063	85	SCG	Hard	8-wind	180	70	0.002	Irr; dom.
179	J. J. Curtis	1	4	24	1892	7-inch pipe	1,088	1,063	90		do	do	150	120	0.008	Irr; dom.
180	A. C. Harvey	1	4	24	1898	7-inch pipe	1,088	1,088	600	GC	do	Centrifugal; 12 gas	400	1,200	2.250	Irr.
181	W. A. Thomas	1	4	24			1,078	1,076				Artesian				
182	L. S. Dart	1	4	25	1890	7-inch pipe	1,075	1,055	80		Hard	12 wind	150		0.002	Dom.

183	Anderson estate	1	4	25		8-inch pipe 4.5-inch pipe	1,098		450 150		Soft	Centrifugal; 25 gas		2,275	0.250	Irr.
184	A. Hunt	1	4	27	1889	7-inch pipe	1,006	1,005	127		Hard	Artesian	200		0.100	Irr; dom.
185	do	1	4	27	1889	7-inch pipe	1,001	1,001	57			do	90		0.800	Irr.
186	do	1	4	27	1895	9½-inch pipe	1,004	1,004	280	SCG		do	1,100		0.400	Irr.
187	do	1	4	27	1894	7-inch pipe	1,007	1,007	200			do	500			Irr.
188	No record															
189	E. M. Cooley	1	4	27	1889	7-inch pipe	1,019	959	86		Hard	12 wind	150	100		Irr; dom.
190	H. L. Drew	1	4	21		8-inch pipe	980	980	200		do	Artesian			0.010	Dom.
191	C. C. Cooley	1	4	27	1895	7-inch pipe	998	928	85		do	12 wind	150	100		Dom.
192	P. Filance	1	4	27	1887	10-inch pipe	983	983	250		Soft	Artesian	1,000		1.200	Irr.
193	Filance estate	1	4	27	1880	3-inch pipe (3)	984	984	75 85 90		do	do			0.900	Irr; dom.
194	O. A. Byrne	1	4	21		2-inch pipe	984	980				Hand		5		Dom.
195	Harry Whaley	1	4	34	1890	7-inch pipe	1,150	1,115	100		Hard	8 wind			0.001	Dom.
196	Thomas N. Hunt	1	4	34	1890	D, 3 feet dia	1,117	1,090	123			16 wind	750	100		Dom.
197	Mr. Blair	1	4	34	1899	D, 5 by 5 feet	1,115	1,109	16			Never used				
198	Ignacio Reyes	1	4	34	1895	Dug	1,182	1,172	13		Soft		15	3		Dom.
199	Washington School	1	4	27		7-inch pipe	1,043	966	129			8 wind		90		Dom.
200	S. A. Pooles	1	4	33	1890	7-inch pipe	1,015	955	75		Hard	12 wind		500	0.005	
201	Fred Pooles	1	4	33	1884	7-inch pipe	955	907	52			8 wind				Dom.
202	Mrs. C. A. Peake	1	4	33	1880	2-inch pipe	950	936	18		Hard	Hand	10			Dom.
203	Chas. Green	1	4	33		3-inch pipe	944		3		do	Wind				Dom.
204	J. D. Warner	1	4	28	1884	1½-inch pipe	938	927	13		do	Hand	10			Dom.
205	do	1	4	28	1898	1½-inch pipe	926	916	13		do	do	8			Dom.
206	do	1	4	28	1894	10-inch pipe	941	935	515	GCR	do		2,455			
207	Geo. Cooley, sr	1	4	27	1894	7-inch pipe	978	952	72	G		12 wind		125	0.005	Irr; dom.
208	C. A. Poole	1	4	27	1900	7-inch pipe	1,002	984	50	SG	Hard	Hand	110			Dom.
209	A. A. Warren	1	4	33	1885	2-inch pipe	936	929	25		do	12 wind	15	150	0.002	Irr; dom.
210	W. Riverside Water Co.	1	4	32			950	944	112	GR	do	30 compressor		1,275		Irr.
211	J. M. Snodgrass	1	4	28	1898	D, 10 feet dia	931	927	13	GS	do	Bucket pump; eng	50	600	0.500	Irr.
212	do	1	4	28	1898	D, 2 feet dia	923	920	7.5	GS	do	12 wind	10	50	0.008	Irr.
213	A. A. Warren	1	4	33	1897	2-inch pipe	943	936	15		do	Hand	15	5		Dom.
214	S. P. R. R. Co	1	4	21	1882	7-inch pipe	958	915	45		do	12 wind			0.005	Dom.
215	Frank Parody	1	4	28	1900	Dug	955	934	33	S	do	Hand		12		Dom.
216	Martin Gahm	1	4	21	1888	D, 3 by 3 feet	964	927	41		do	8 wind	50	75	0.005	Dom.
217	W. H. Wells	1	4	21	1898	D, 2.5 by 2.5 feet	966	928	44	SG	do	Hand	6			Dom.
218	C. G. Turner	1	4	21	1895	7-inch pipe	966		70		do	12 wind				
219	G. B. Kinyon	1	4	21	1888	D, 3 by 3 feet	948	934	25		Soft	Wind	25	500		Irr; dom.
220	J. F. Stuchberry	1	4	21	1886	D, 3.5 by 3.5 feet	952	933	22	CSG	do	8 wind	30	90	0.007	Irr; dom.
221	J. H. Vaughan	1	4	21	1886	D, 4 feet dia	955	934	27		Hard	12 wind	48	75	0.009	Irr; dom.
222	Alfred Vaughan	1	4	21	1900	D, 4 feet dia	959	928	34			do	62	155		Irr.
223	W. L. Vaughan	1	4	21	1884	D, 4 feet dia	965				Hard	do			0.009	Irr; dom.
224	H. D. Young	1	4	21	1890	D, 2 feet dia	963	931	40		Soft	Hand	40			Dom.

[a] Wells 159 to 164 are connected. From this group a 40-horsepower gasoline engine and centrifugal pump raise 2.66 second-feet of water. These wells were artesian until 1900.

NOTE.—Flow of wells Nos. 104 to 114 and 170 was measured on completion of wells. Flow of wells Nos. 115 to 136 and 155 to 164 is given for October, 1892. No other records of flow of these wells. Wells Nos. 137 to 154 and 165 to 168 are in Redlands quadrangle, as are Nos. 391 to 412. Flow of these wells is given for October, 1892.

Wells in San Bernardino quadrangle—Continued.

No. of well.	Owner of well.	Location (T. R. S.).	Year completed.	Class of well.	Elevation of surface.	Elevation of water.	Depth of well.	Strata.	Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
		S. W.			Feet.	Feet.	Feet.						Sec.-ft.	
225	J. H. Dodson	1 4 21	1885	D, 4 feet dia	969	926	50		Soft	8 wind		$105	0.008	Irr; dom.
226	Henry Kaiser	1 4 21	1892	D, 4 feet dia	964	922	43		do	12 wind	$84		0.006	Irr; dom.
227	H. C. Dodson	1 4 21	1892	D, 2 feet dia	968	928	55		do	8 wind		212		Irr; dom.
228	John Benner	1 4 21	1880	D, 4 feet dia	970	916	62			12 wind			0.002	Irr; dom.
229	Tom Moran	1 4 21		D, 4 feet dia	974	921	54		Hard	Hand			Small.	Dom.
230	T. Allen	1 4 21	1880	D, 4 feet dia	978	924	68		Soft	14 wind		155	0.001	Dom.
231	S. A. Woodard	1 4 21	1882	D, 4.5 feet dia	984	928	69		Hard	12 wind			0.009	Irr; dom.
232	Los Angeles Bdg. Co.	1 4 21		D, 4 by 4 feet	1,000	Dry.	70			10 wind				
233	J. A. Coburn	1 4 16	1890	D, 4 by 4 feet	1,000	934	80		Hard	12 wind			0.005	Irr; dom.
234	Miss B. Top	1 4 16			1,038	1,038	3			8 wind	5	66	0.002	Irr; dom.
235	Byron Waters	1 4 16	1893	D, 9.5 by 9.5 feet and 5 by 5 feet.	1,019	991	28			Centrifugal; 8 electric.	300	876	0.6	Irr; dom.
235a	do	1 4 16	1889	3-inch pipe	1,019		220			Artesian	700		0.005	Irr; dom.
236	Dr. Rowl			Pipe						do				
237	do			Pipe					Sulph.	do				
238	Homer Jones	1 4 16	1895	3-inch pipe	1,023	1,010	300		do	8 wind			0.002	Irr; dom.
239	Mrs. M. G. Hammel	1 4 16			1,008	1,000	83		Hard	do		75	0.002	Irr; dom.
240	Riverside Trust Co	1 4 23		7-inch pipe	1,000				do	Hand				Dom.
241	F. S. West	1 4 23	1897	2-inch pipe	998									Irr; dom.
242	Mrs. E. A. Paine	1 4 22	1896	3-inch pipe	1,000	1,000	109	SCG	Hard	Artesian		75	0.04	Irr; dom.
243	M. B. Warren	1 4 22	1885	4-inch pipe	996	996	125		do	do			0.01	Irr; dom.
243a	do	50′ SE. from 243	1899	3-inch pipe	997	997	130	SCG		do			0.25	Irr.
244	do	1 4 22	1880	2-inch pipe	998	998	125		Hard	do			0.041	Irr; dom.
244a	do	20′ SW. from 244	1899	3-inch pipe	997	997			do	do			0.178	Irr; dom.
245	C. E. Bishop	1 4 23	1882	3-inch pipe	1,001	1,001	94		do	do	125		0.02	Irr; dom.
245a	do	1 4 23	1888	7-inch pipe	1,004	1,004	94	SC	do	do			0.02	Irr; dom.
246	Wm. E. Everett	1 4 22	1898	3-inch pipe	1,001	1,001	96		do	do	100		0.25	Irr; dom.
247	Bob Gomer	1 4 15	1890	3-inch pipe	984				do					
248	John Welsh	1 4 23		3-inch pipe	1,007	1,007	100		Hard	Artesian			0.083	Irr; dom.
249	S. B. Parish	1 4 14	1892	10-inch pipe	1,019	1,019	540		Soft	do	2,500		0.40	Irr.
250	do	1 4 14	1885	6-inch pipe	1,017	1,015	104		Hard		300			
251	do	1 4 14	1889	2-inch pipe	1,016		100		do		150			
252	do	1 4 14	1870	1½-inch pipe	1,014	1,014	83		do	Artesian			0.004	
253	Mrs. Elizabeth Case	1 4 14	1898	3-inch pipe	1,007	1,007	91		do	do	85		0.115	Irr; dom.
254	do	1 4 14	1892	7-inch pipe	1,009	1,009	260		do	do	500		0.2	Irr.
254a	W. G. Merrilees	1 4 14	1893	7-inch pipe	1,009	1,009	211		do	do			0.14	Irr.
254b	do	1 4 14	1897	3-inch pipe	1,009	1,009	86		do	do			Small.	Irr.
255	Wm. Stewart	1 4 15	1898	8-inch pipe	1,004	1,004	315		do	do			[a] 1.14	Irr.
256	do	1 4 15	1898	9-inch pipe	1,005	1,005	85		do	do			[b] 0.2	Irr.

257	do	1	4	15		1¼-inch pipe	1,004	1,004			do	do			Small.	Dom.
259	do	1	4	15		7-inch pipe	1,002				do					Irr.
260	John Sullivan	1	4	14	1874	2-inch pipe	1,021		82				100		(c)	Irr; dom.
261	do	1	4	14	1893	3-inch pipe	1,024	1,024	210		Hard	Artesian	325		0.002	
263	do	1	4	14	1884	7-inch pipe	1,025	1,023	84				80		(d)	
264	do	1	4	14	1871	2-inch pipe	1,037		90						(d)	
265		1	4	14	1892	2-inch pipe	1,022		92			Artesian			0.002	Dom.
266	Wm. Baker	1	4	14	1870	1.5-inch pipe	1,022	1,022	96		Hard	do	130		Small.	Dom.
267	do	1	4	14	1899	3-inch pipe	1,024	1,024	271	SGC	do	do	435		0.178	Dom; irr.
268	P. J. Clevenger	1	4	14		2-inch pipe	1,030					10 electric; centrifugal.			(e)	
269	do	1	4	14	1897	10-inch pipe	1,043		150						0.5	Irr.
270	Henry Warren	1	4	14	1883	2-inch pipe	1,033	1,023	106				150		(d)	Dom; irr.
271	do	1	4	14	1890	3-inch pipe	1,033	1,023	100			12 wind	100	160	(d)	Dom; irr.
272	John Sullivan	1	4	14	1898	3-inch pipe	1,024	1,024	214		Hard	Artesian	300		0.178	Irr.
273	Henry Warren	1	4	14	1880	7-inch pipe	1,036	1,026	106				200		(e)	Not used.
274	do	1	4	14	1880	7-inch pipe	1,038	1,028	220				500		(f)	Not used.
275	do	1	4	14	1893	10-inch pipe	1,039	1,039	640			Artesian	3,000		0.386	Irr.
276	Frank Feri	1	4	14		2-inch pipe	1,034					Hand			(g)	Dom.
277	G. Renwick	1	4	8		6-inch pipe	1,090	1,055	186		Soft	8 wind			Small.	Dom.
278	Orange Land and Water Co.	1	4	8		7-inch pipe	1,089	1,069	225		do	Centrifugal; 20 compressor; 3 wells in group together.			1.64	Dom; irr.
279	Callahan estate	1	4	20	1886	D, 4 by 4 feet	1,009	933	84			12 wind				
280	E. Memory	1	4	20	1886	D, 4 by 4 feet	982	927	60		Hard	do			Small.	Dom.
281	F. A. Cleveland	1	4	8	1898	2-inch pipe	1,072		90			8 wind	47	40	Small.	Dom.
282	C. H. Westmyer	1	4	8	1897	3-inch pipe	1,069	1,062	94	GSC	Soft	do	74	100	Small.	Dom; irr.
283	W. W. Brison	1	4	9	1899	2-inch pipe	1,062	1,052	99	SG	do	10 wind	100	200	Small.	Dom.
284	G. F. Woods	1	4	9	1900	8-inch pipe	1,059	1,049	140		do	do	300	350	0.008	Dom; irr.
285	do	1	4	9	1887	7-inch pipe	1,060	1,060	300						None.	
286	City of Colton	1	4	8		10-inch pipe (2) 7-inch pipe (2)	1,065		200-640			Centrifugal; 20 electric.		2,000	2.500	Dom; irr.
287	Isaac Jameson	1	4	8	1898	8-inch pipe	1,070	1,050	90		Hard	12 wind	126	275	0.015	Dom; irr.
288	J. Collins	1	4	8	1887	3-inch pipe	1,054		75			10 wind			Small.	Irr; dom.
289	J. C. Ralphs	1	4	9	1899	10-inch pipe	1,047	1,016	202		Soft	12 wind	500	200	Small.	Irr; dom.
290	Los Angeles Bdg. Co.	1	4	9	1893	10-inch pipe	1,052		160		do	8 gas; centrifugal			0.8	Irr.
291	V. Herkelrath	1	4	15	1882	2-inch pipe	979	979			do	Artesian	70		0.072	Dom.
292	do	1	4	15	1880	2-inch pipe	980	980			do	do	175		0.119	Irr.
293	Mrs. Nowland	1	4	15	1875	2-inch pipe	980	980	160			do	275			Irr.
294	M. H. Hurd	1	4	15	1887	2-inch pipe	983				Hard	do				Dom.
295	Mrs. N. H. Ball	1	4	15	1894	7-inch pipe	996	996	253		Soft	do	500		0.262	Irr.
296	Los Angeles Bdg. Co.	1	4	9		10-inch pipe	1,051	1,049	446			do			0.4	Irr.
297	do	1	4	9		10-inch pipe	1,050	1,048	451			do			0.4	Irr.
298	Mrs. N. H. Ball	1	4	15	1886	3-inch pipe	992	992	107		Soft	do	250			Dom.
299	W. Beck	1	4	15	1892	3-inch pipe	998	998	204		do	do				Irr.
300	H. Klueter	1	4	10	1885	3-inch pipe	1,006	1,006	200		do	do	300		0.074	Dom; irr.
301	do	1	4	10	1887	3-inch pipe	1,005	1,005	206		Soft	do	328			Irr.
302	do	1	4	10	1887	3-inch pipe	1,005	1,005	132		do	do	159		0.518	Irr.
303	do	1	4	10	1897	3-inch pipe	1,003	1,003	135		do	do	125		0.006	Irr.

[a] 1899.
[b] 1898.
[c] Stopped flowing in 1895.
[d] Stopped flowing in 1898.
[e] Stopped flowing in 1889.
[f] Stopped flowing in 1890.
[g] Stopped flowing in May, 1900.

NOTE.—No record for Nos. 258 and 262.

Wells in San Bernardino quadrangle—Continued.

No. of well.	Owner of well.	Location (T.R.S.).	Year completed.	Class of well.	Elevation of surface.	Elevation of water.	Depth of well.	Strata.	Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
		S. W.			*Feet.*	*Feet.*	*Feet.*						*Sec.-ft.*	
304	Stephen Wood	1 4 11	1894	3-inch pipe	1,010	1,010	160		Soft	Artesian			Small.	Dom.
305	W. B. Barton	1 4 14	1883	2-inch pipe	1,041		100		do	12 wind		$216	Small.	Dom.
306	Stephen Wood	1 4 11	1880	3-inch pipe	1,022		164			8 wind			Small.	Stock.
307	F. M. Keller	1 4 11	1882	3-inch pipe	1,024	1,024	267		Soft	Artesian	$500		0.02	Dom.
308	W. B. Barton	1 4 13	1892	10-inch pipe	1,045	1,033	115		do	9 gas; centrifugal			0.209	Irr.
309	A. J. Downer	1 4 13	1889	3-inch pipe	1,045		190		do	12 wind	125	50	Small.	Dom.
310	Edwin Martin	1 4 13		3-inch pipe	1,045	1,033	215		do	Hand			Small.	Dom.
311	Lucas Hoagland	1 4 13	1876	2-inch pipe	1,049	1,039	80		do	do	75		Small.	Dom.
312	do	1 4 13	1884	3-inch pipe	1,050	1,040	250		do	8 wind	250	75	Small.	Stock.
313	do	1 4 12	1884	2-inch pipe	1,047		100		do		100			Not used.
314	R. F. Garner	1 4 10	1888		1,019		200			Artesian			Small.	Dom.
315		1 4 12		10-inch pipe	1,059	1,059	682+			do			0.123	Stock.
		N. W.												
316	Geo. M. Cooley	1 4 36	1892	7-inch pipe	1,150	1,108	66		Soft	12 wind		500		Irr; dom.
317	do	1 4 36	1895	11-inch pipe	1,150	1,108	80			9 gas		1,500	0.6	Irr.
317a	do	1 4 36	1895	10-inch pipe	1,150	1,108	80			9½ cylinder pumps				Irr.
318	E. J. Stiles	1 4 35	1898	7-inch pipe	1,196	1,157	48		Soft	10 wind	40	160	Small.	Dom; st.
319	Jas. Dickson	1 4 35	1888	10-inch pipe	1,179	1,145	44		do	12 wind		135	Small.	Dom.
320	J. G. Wood	1 4 35	1884	7-inch pipe	1,124	1,090	44		do	do		200	Small.	Dom.
321	do	1 4 36	1885	11-inch pipe	1,140	1,092	64		do	Cylinder pump; 5 gas	240	600	0.125	Irr.
322	M. E. Myers	1 4 35	1890	2-inch pipe	1,111	1,089	310		Hard	12 wind				Dom; irr
		S. W.												
323	J. S. Bean	1 4 3	1889	3-inch pipe	1,108	1,108	210			Artesian	200		0.1	Irr.
324	do	1 4 3	1898	10-inch pipe	1,108	1,108	524		Hard	do	1,100		0.9	Irr.
		N. W.												
325	J. F. Johnson	1 4 34	1890	7-inch pipe	1,098	1,076	39		do	Hand				Not used.
326	Oscar Perris	1 4 26			1,177		96			Steam; power				Irr.
327	S. G. Ramsey	1 4 25	1896	10-inch pipe	1,190	1,125	90	SC		Power; 10 gas	160	1,200	0.3	Irr.
328	Saml. S. Ford	1 4 26	1898	D, 3 feet dia	1,185	No water.	58			Wind		225	None.	
329	Mescupiabe L. & W. Co.	1 4 23	1899	7-inch pipe	1,288	1,143	402		Hard	Power; 15 gas	1,200	2,000	0.5	Dom; st; irr.
330	do	1 4 26	1892	7-inch pipe	1,222	No water.	102			Wind	300	250	None.	
331	Mrs. Anne C. Severance.	1 4 26	1895	7-inch pipe	1,227	No water.	106			12 wind	300	900	None.	
332	Mrs. S. A. Smith	1 4 27	1894	7-inch pipe	1,224	1,124	140		Soft	16 wind		800	0.010	Irr; dom.
333	F. M. Johnson	1 4 34	1899	10-inch pipe	1,117	1,095	600			10 gas; cylinder pump.	1,160	800	0.230	Irr.
334	do	1 4 34	1890	12-inch pipe	1,112	1,084	40			Wind			Small.	St; dom.

335	H. H. Fitting	1	4	35	1885	7-inch pipe	1,124		44		Soft	do			Small.	St; dom
336	do	1	4	35	1888	D, 6 by 6 feet	1,135	No water.	47			4½ gas; cylinder pump.	100	500	None.	
337	do	1	4	35	1886	3-inch pipe	1,131		325				1,000		Dry.	
338	C. Hansen	1	4	35	1895	7-inch pipe	1,127	1,090	39		Soft	8 wind		200	Small.	St; dom.
339	N. Holen	1	4	35	1895	7-inch pipe	1,127	1,090	47		do				Small.	St; dom.
340	John Anderson	1	4	34	1885	7-inch pipe	1,130		90		do	8 wind	114	100	Small.	St; dom.
341	H. N. Stones	1	4	34	1884	7-inch pipe	1,141	1,087	85		do	do		125	Small.	St; dom.
342	M. F. Swing	1	4	34	1891	7-inch pipe	1,151		93		do	12 wind		220		St; dom.
343	do	1	4	34	1894	7-inch pipe	1,152		87		do	do			Small.	Irr.
344	A. R. Togg	1	4	34	1891	7-inch pipe	1,160		100		do	do				Irr; dom.
345	F. L. Smith	1	4	34	1897	7-inch pipe	1,163		106		do	10 wind	105	135	0.002	Irr; dom.
346	John W. Anderson	1	4	34	1880	7-inch pipe	1,165	1,103	70		do	do	75	175	0.002	Irr.
347	do	1	4	34	1900	7-inch pipe	1,166	1,103	113		do	16 wind	125	225	0.004	Irr.
348	S. E. Pearson	1	4	27	1899	7-inch pipe	1,182	1,107	104		do	12 wind	135	60	Small.	Irr; dom.
349	R. Meacham	1	4	27	1900	7-inch pipe	1,183		110		do	do			Small.	Irr; dom.
350	do	1	4	27	1890	7-inch pipe	1,172	No water.	64			do			None.	
351	J. H. Taylor	1	4	27	1896	7-inch pipe	1,188	No water.	62		Soft	8 wind	50	100	None.	
352	W. G. Warner	1	4	27	1899	7-inch pipe	1,189	1,119	80			10 steam				Not used.
353	F. D. Olmstead	1	4	27	1895	7-inch pipe	1,190		101		Soft	12 wind		100	Small.	Irr; dom.
354	S. F. Kelley	1	4	28	1897	7-inch pipe	1,170	1,121	115		Hard	8 wind			Small.	Irr; dom.
355	S. F. Kelley et al	1	4	28	1900	12-inch pipe	1,185	1,127	208			20 electric; centrifugal.	1,700	1,171	0.9	Irr.
355a	do	1	4	28	1899	10-inch pipe	1,185	1,127	460							
356	H. C. Ward	1	4	28		7-inch pipe	1,177	1,118	120			12 wind			Small.	Irr.
357	S. H. Johnson	1	4	28	1885	7-inch pipe	1,182	1,122	84		Soft	10 wind		250	Small.	Dom.
358	H. Giddings	1	4	28	1898	7-inch pipe	1,215	1,148	73		do	15 wind		125		Dom.
359	W. G. Rowland	1	4	28	1893	7-inch pipe	1,224	1,156	112		Hard	Geared pump; 3 gas	125	625	0.1	Irr.
360	Fred. Heilemann	1	4	32	1889	7-inch pipe	1,227	1,147	146		do	16 wind	200	750	0.008	Irr; dom.
361	do	1	4	32	1894	7-inch pipe	1,228	1,148	129		do	18 wind			0.012	Irr; dom.
362	do	1	4	29	1890	10-inch pipe; 8-inch pipe; 6⅝-inch pipe	1,245	1,155	1,025				7,000		(a)	
363	B. E. Wheeler	1	4	29	1898	10-inch pipe	1,258	1,152	125		Hard	Plunger pump; 5 gas.	300	800		Irr; dom.
364	F. Alvarado	1	4	32	1900	7-inch pipe	1,188	1,135	93							Not used.
365	A. B. Hancock	S. W. 1	4	5	1896	7-inch pipe	1,170		56		Hard	12 wind	125	100	Small.	Dom; etc.
366	do	1	4	5	1882	7-inch pipe	1,169		56		do	do				Dom; etc.
367	D. W. White	N. W. 1	4	4	1871	7-inch pipe	1,109	1,089	195			Gas; centrifugal; 8 wind.	1,200	200	0.400	Irr; dom.
368	W. F. Holcomb	S. W. 1	4	33		7-inch pipe	1,115	1,089	37		Soft				Small.	Dom.
369	Alex. Wixom	N. W. 1	4	4	1899	8-inch pipe	1,117		45		Hard	12 wind	50	148	Small.	Dom.
370	F. L. Holcomb	S. W. 1	4	33	1885	7-inch pipe	1,128	1,100	47		do	do	100	150	Small.	Dom.
371	do	1	4	33	1885	7-inch pipe	1,133	1,103	47		do	do	100	150	Small.	St.
372	J. J. Whitney	1	4	4	1884	Pipe	1,129	1,101	112		do	Wind		400	Small.	Dom; st.
373	P. B. Hockaday	1	4	4	1887	7-inch pipe	1,133		110		Soft	12 wind		500	Small.	Dom; irr.
374	J. J. Morris, sr	1	4	5	1890	8-inch pipe	1,137	1,109	53		do	10 wind		75	Small.	Dom; irr

[a] Tools left in well.

Wells in San Bernardino quadrangle—Continued.

No. of well.	Owner of well.	Location (T.R.S.).	Year completed.	Class of well.	Elevation of surface.	Elevation of water.	Depth of well.	Strata.	Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
		S. W.			*Feet.*	*Feet.*	*Feet.*						*Sec.-ft.*	
375	Dexter Field	1 4 5	1870	6-inch pipe	1,147	1,112	45		Hard	10 wind			Small.	Dom.
		N. W.												
376	C. A. Muscott	1 4 32	1886	8-inch pipe	1,158	1,115	78		Soft	12 wind	$100	$250		Dom; irr.
377	J. W. Roberts	1 4 27	1899	10-inch pipe	1,210	1,155	160	GC	do	Plunger pump; 5 electric.	400	900	0.24	Dom; irr.
378	T. C. Parker	1 4 32	1886	Pipe	1,205		98		Hard	12 wind; 3 gas		550		Dom; irr.
379	P. Oldecker	1 4 33	1893	7-inch pipe	1,195		133		do	Geared pump; 2 gas.		400	0.10	Dom; irr.
380	A. Peterson	1 4 33	1890	7-inch pipe	1,192	1,134	76	SG	Soft	12 wind	50	100	Small.	Dom; irr.
381	C. A. Bruckman	1 4 32	1894	10-inch pipe	1,221	1,151	146		do	Geared pump; 16 gas.	325	775	0.36	Irr.
382	do	1 4 32	1892	7-inch pipe	1,215	1,145	84	SCG	do	12 wind	115	300		Irr.
383	do	1 4 32	1892	7-inch pipe	1,214	1,144	85		do	Geared pump; 5 gas.	115	625	0.042	Irr.
384	do	1 4 32	1890	7-inch pipe	1,192	1,134	85		do	12 wind	115	250	Small.	Dom.
385	Wilson & Wheat	1 4 32	1890	7-inch pipe	1,188	1,128	82		do	16 wind				Dom; irr.
386	E. D. Palmer	1 4 33	1894	7-inch pipe	1,184		80		Hard	14 wind			Small.	Dom; irr.
387	C. G. Leonhardt	1 4 32	1890	7-inch pipe	1,182		85		Soft	12 wind	115	192	Small.	Dom; irr.
388	do	1 4 32	1899	8-inch pipe	1,197	1,133	90			do	125	297	0.006	Irr.
389	S. E. A. Palmer	1 4 33	1887	7-inch pipe	1,176	1,124	92		Hard	14 wind	150	350	0.003	Dom; irr.
390	Fred F. Palmer	1 4 33	1899	D, 4 by 6 feet; 7-inch pipe	1,189	1,134	85		do	Duplex; steam	300	500	0.036	Irr.
391	W. D. Wilson	1 4 32	1893	8-inch pipe	1,203	1,138	94		do	12 wind				Irr.
392	S. H. Harmon	1 4 32	1893	10-inch pipe	1,194	1,132	133		do	Geared pump; 5 gas.	1,300	(a)	0.020	Irr.
393	S. W. Harmon	1 4 32	1882	7-inch pipe	1,181	1,128	75		do	12 wind	50	220		Dom; irr.
394	J. O. Slatter	1 4 33	1890	7-inch pipe	1,155		100		Soft	do		150	Small.	Dom.
395	C. N. Damron	1 4 33		7-inch pipe	1,120	1,093	47		Hard	8 wind			Small.	Dom.
396	Mrs. Amy McCrary	1 4 33	1899		1,138	1,112	91		Soft	Hand			Small.	Dom.
397	Thos. Webster	1 4 33	1898	7-inch pipe	1,134					12 wind				Dom.
398	N. M. Swarthout	1 4 33	1885	7-inch pipe	1,142	1,115	75		Hard	8 wind	150	100	Small.	Dom.
399	do	1 4 33	1895	10-inch pipe	1,169		80			Horse	100	35	Small.	Irr.
400	J. H. Lytle	1 4 33	1885	7-inch pipe	1,166	1,135	79		Hard	12 wind	75	50	Small.	Dom; irr.
401	H. S. Davidson	1 4 33	1880	7-inch pipe	1,158		56		Hard	do		500		Dom; irr.
402	N. Swarthout	1 4 33	1885	7-inch pipe	1,142	1,108	55		do	8 wind			Small.	Dom.
403	G. W. Evans	1 4 33	1887	6-inch pipe	1,128	1,096	75		do	do			Small.	Dom.
404	R. M. Bradley	1 4 33	1884	7-inch pipe	1,101	1,082	90			12 wind			Small.	Dom.
405	Mrs. Sarah Abel	1 4 33	1880	D, 3 feet dia	1,109	1,088	22		Soft	Bucket			Small.	Dom.
406	R. Poppett	1 4 34	1885	7-inch pipe	1,109	1,085	45			12 wind	50	140	Small.	Dom; irr.
407	G. Johnson	1 4 34	1890	7-inch pipe	1,114	1,087	47		Hard	8 wind	60	60	Small.	Dom; irr.
408	E. G. Fish	1 4 34	1889	2-inch pipe	1,133		425		do	do	1,000		Small.	Dom; irr.
409	C. Cohn	1 4 34		7-inch pipe	1,118	1,089			Soft	10 wind			Small.	Dom.
410	O. B. Peck	1 4 34	1888	7-inch pipe	1,147		115		do	14 wind			Small.	Dom; irr.
411	K. P. Stephens	1 4 34	1893	7-inch pipe	1,104	1,114	65		do	do			0.003	Dom; irr.

412	Jno. Y. Anderson	1 4 34	1900	8-inch pipe 12-inch pipe	1,165	1,109	150 400				2,000			Not used.
413	Jno. Lawrence	1 4 34	1897	7-inch pipe	1,091	1,076	42		Soft	8 wind		160	Small.	Dom.
414	J. C. Wees	1 4 34	1898	7-inch pipe	1,097	1,073	46		do	do				Dom.
415	Thos. J. Rennous	1 4 34	1900	7-inch pipe	1,133	1,101	72		do	10 wind	72	150	Small.	Dom; irr.
416	H. H. Ham	1 4 34	1888	7-inch pipe	1,121	1,090	52		Hard	8 wind	75	100	Small.	Dom; irr.
417	W. M. Jenkins	1 4 34	1884	7-inch pipe	1,118	1,088	52			12 wind			Small.	Dom; irr.
418	Oscar Wees	1 4 34	1885	7-inch pipe	1,108		48		Soft	8 wind			Small.	Dom.
419	M. W. Davis	1 4 34	1898	7-inch pipe	1,100		42		do	do	40	90		Dom.
420	P. W. Heap, jr	1 4 34	1894	7-inch pipe	1,128	1,088	58		do	12 wind	60	125	0.002	Dom; irr.
421	B. M. Wall	1 4 34 S. W.	1897	8-inch pipe	1,100		137		Hard	8 wind			Small.	Dom; irr.
422	E. Case	1 4 3	1899	8-inch pipe	1,086	1,073	50		Soft	Hand			Small.	Dom.
423	Jno. E. Garner	1 4 2 N. W.	1900	8-inch pipe	1,087	1,073	334			Centrifugal; 8 gas	750	750	0.800	Irr; etc.
424	do	1 4 35	1888	10-inch pipe 7-inch pipe	1,164	1,108	420		Hard	Centrifugal; 20 electric.	1,500	3,000	1.200	Irr.
425	Colton City Water Co.	1 4 31	1900	10-inch pipe	1,202		208			Centrifugal; 25 gas			1.480	Irr; dom.
426	San Bernardino City Waterworks.	1 5 36	1895 1900	2 11-inch pipes 12-inch pipe	1,239	1,207	320 550 800		Soft	Centrifugal; 25 gas			1.400	City supply.
427	Riverside-Highland Water Co.	1 4 31	1900	10-inch pipe	1,218	1,204	320							Not used.
428	do	1 5 36	1892	10-inch pipe	1,246	1,211	650			Centrifugal; 22 gas	5,000	1,100	1.600	Irr; dom.
429	do	1 4 31	1893	2 10-inch pipes	1,250	1,201	350 300			Centrifugal; 30 electric.	3,000	2,500	2.000	Irr; dom.
430	do	1 4 31		2 10-inch pipes	1,258	1,203	500-600			do	3,000	2,500	2.800	Irr; dom.
431	Rialto Irrig. Dist. Citizens' Water Co	1 5 36	1891	2 10-inch pipes	1,255	1,204	450		Hard	Centrifugal; turbine	1,500		1.300	Irr; dom.
432	do	1 5 36	1894	10-inch pipe	1,260	1,207	460			Centrifugal; 20 gas	1,800	6,000	0.720	Irr; dom.
433	F. E. Watkins	1 5 36	1888	10-inch pipe	1,266	1,210	621		Soft	2 25 compressors			0.890	Irr.
434	Lytle Creek Water and Imp. Co.	1 5 36	1900	3 12-inch pipes	1,290	1,215	226	Gravel	do	Duplex steam	3,061	3,500	[b]2.200	Irr.
435	Rialto Irrig. Dist.	1 5 25	1897	10-inch pipe	1,333	1,303	520			Centrifugal; 30 electric.	1,500	2,000	1.800	Irr; dom.
436	do	1 5 25	1894	10-inch pipe	1,342	1,306	432		Hard	do	1,500	2,000	1.500	Irr; dom.
437	Anglo-American Canaigre Co.	1 5 25	1899	D, 7 by 9 feet (2)	1,337	1,307	45							Not used.
438	F. E. Watkins	1 5 25	1898	10-inch pipe	1,390	1,251	381				2,000			Not used.
439	Riverside-Highland Water Co.	1 4 31 S. W.		20 wells	1,200-1,225								([c])	Irr.
440		1 4 4		D, 4 by 4 feet	1,089	1,083	7			Hand				Stock.
441	M. E. Brooks	1 4 5	1886	3-inch pipe	1,102		132		Hard	8 wind				Dom; st; irr.
442	do	1 4 5		3-inch pipe	1,105		140			12 wind			Small.	Irr.
443	Mrs. Mary Bemis	1 4 5	1888	Pipe	1,113		132		Hard	Hand			Small.	Dom.
444	A. W. Bemis	1 4 5	1890	8-inch pipe	1,118	1,101	48		Soft	12 wind			Small.	Dom.
445	do	1 4 5	1894	10-inch pipe	1,114	1,104	50			Centrifugal; 3 gas		250	0.014	Irr.
446	D. F. Probst	1 4 4	1886	7-inch pipe	1,085	1,070	36		Soft	10 wind			Small.	Dom.
447	Mrs. A. Tompkins	1 4 5	1882	7-inch pipe	1,115		212		do	Wind	1,000	175	Small.	Dom; irr.

[a] Included in cost of well.

[b] Two wells.

[c] These 20 wells have nearly all ceased flowing.

Wells in San Bernardino quadrangle—Continued.

No. of well.	Owner of well.	Location (T. R. S.).			Year completed.	Class of well.	Elevation of surface.	Elevation of water.	Depth of well.	Strata.	Quality of water.	Method of lift.	Cost of well.	Cost of machinery.	Quantity of water.	Use of water.
		S.		W.			Feet.	Feet.	Feet.						Sec.-ft.	
448	J. Hancock	1	4	5	1875	7-inch pipe	1,138	1,092	128		Hard	Wind			Small.	Dom; irr.
449	M. D. Reynolds	1	4	5	1900	10-inch pipe	1,136	1,106	146		Soft	Centrifugal; 25 gas	$300	$1,400	0.027	Irr.
450	do	1	4	5	1898	7-inch pipe	1,116	1,094	40		do	8 wind	60	150	Small.	Dom.
451	Mrs. M. Lord	1	4	4	1888	3-inch pipe	1,125		150		Hard	10 wind			Small.	Dom.
452	John Marshall	1	4	5	1888	7-inch pipe	1,128	1,103	42		Soft	do			Small.	Dom.
453	I. W. Hazlett	1	4	4	1900	7-inch pipe	1,101	1,082	142		Hard	12 wind	283		0.002	Dom.
454	Mrs. Alice Wixom	1	4	4		7-inch pipe	1,067	1,055	22		Soft	do			Small.	Dom.
455	Mrs. Irving	1	4	4		7-inch pipe	1,099	1,078	100			8 wind			Small.	Dom.
456	J. B. Kitring and R. H. Hacker.	1	4	4	1895	2-inch pipe	1,085	1,070 in 1899.	152		Hard	do		260	Small.	Dom.
457	J. F. Cadd	1	4	4	1888	7-inch pipe	1,068	1,057	40		do	Hand		40	Small.	Dom.
458	H. E. Gardner	1	4	5		3-inch pipe	1,089	1,075			Soft	8 wind			Small.	Dom.
459	Mrs. Marilla Smith	1	4	5	1889	2-inch pipe	1,094	1,079	122		do	Wind	122	150	Small.	Dom.
460	San Bernardino County Hospital.	1	4	8	1898 1899	3-inch pipe 7-inch pipe 10-inch pipe	1,089	1,071	125 125 330		do	Centrifugal; 6 gas			0.300	Irr.
461		1	4	8		2 wells	1,057					Electric				Irr.
462	Riverside Trust Co	1	4	26		9 wells	1,019	1,019				Artesian				Irr.
463	Riverside Water Co	1	4	2			1,036	1,036				do			1.976	Irr.
464	do	1	4	2			1,037	1,037				do			1.930	Irr.
465	do	1	4	2	1900	10-inch pipe	1,040	1,040	544			do			2.896	Irr.
466	do	1	4	2	1900	10-inch pipe	1,041	1,041	582	CSG		do			3.096	Irr.
467	E. D. Meissner	1	4	26	1899	10-inch pipe 8-inch pipe	1,200	1,120	500	GC		Plunger pump; 20 gas	2,600	1,850	0.200	Irr.
468	G. G. Lathrop	1	4	23	1897	7-inch pipe	1,063	1,017	70	GC	Hard.	10 wind	105	130	0.003	Dom; irr.
469	R. L. Dewitt	1	4	26	1897	Dug	1,047	1,028	26	LC	do	Hand				Dom.
470	Charles Morris	1	4	23	1892	D, 12 by 12 feet, 10-inch pipe.	1,078	1,063	80	SGC	do	12 wind	400	140	0.007	Irr.
471	do	1	4	26	1899	10-inch pipe 8-inch pipe 7-inch pipe	1,077		640	SGC	do	Artesian	1,500		0.005	
472	No record															
473	F. S. Waters	1	4	23	1877	2-inch pipe	1,054	1,044	196		Hard.	8 wind	200	145	0.002	Dom; irr.
474	J. H. Hatherley	1	4	23	1888	3-inch pipe	1,555		450			Artesian	1,700		0.140	Irr.
475	J. H. Kelly	1	4	23	1890	8-inch pipe	1,089		382		Hard.	do	2,000		0.400	Dom; irr.
476	do	1	4	23	1891	7-inch pipe	1,074	[a]1,066	500		do	Hand		5		Dom.
477	Mr. Myers	1	4	25	1890	7-inch pipe	1,060		400		do				([a])	
478	W. E. Pedley	1	4	2	1899	10-inch pipe	1,042		510	GR	Soft	Artesian	1,284		2.700	Irr.

[a] Stopped flowing in 1899.

MANUFACTURE OF PORTLAND CEMENT IN SOUTHERN CALIFORNIA.

An important element in the development of an irrigation community is the cost and use of hydraulic cement. Prior to 1893 all of the cement used in southern California came from Europe. This meant a serious financial drain on this section, and the building of a cement-manufacturing plant near Colton which reduced the cost of Portland cement 25 per cent and also kept the remaining 75 per cent at home was therefore an important event in irrigation development as well as building.

The plant of the California Portland Cement Company is three-fourths of a mile from the town of Colton. The company manufactures Portland cement, lime, marble dust, and crushed rock. It employs 70 men, and the capacity of the plant is 300 barrels of cement or 500 barrels of lime daily and an unlimited output of crushed rock. This Portland cement has been extensively used in the various irrigation and hydraulic-power systems of southern California, and has been pronounced by engineers to be equal to imported cement, while it is sold at a much lower price than the foreign article. C. W. Smith, of Pasadena, is now the president of the company and E. Duryee is the chemist.

Probably few, even in the engineering profession, would be inclined to credit the statement, which nevertheless can be corroborated by United States Government reports, that 75 per cent of the Portland cement consumed in the United States during 1900 was manufactured in this country. The only Portland-cement plant on the Pacific coast, however, is the one at Colton, where rotary kilns are in operation. At the outset the Colton company employed an expert to investigate the cement works in the East, of which there are many, and they adopted, as the result of his investigations, what they believe to be the best process. The plant is continuous and largely automatic in operation, machinery being employed to such an extent that 3 barrels of cement per day are obtained for each man employed, as contrasted with 1 barrel per day per man, the ordinary output in European works. The process is protected by letters patent and is American in every respect. The works are very favorably located, being in the center of the semitropical fruit belt of southern California and contiguous to most of the extensive irrigation and hydraulic-power plants of that section, thus insuring an increasing market for the product in the future. In the rear of the mill towers Slover Mountain, with its inexhaustible deposit of pure calcspar and two clay deposits at short distances, which provide abundant crude materials. The company is fortunate in having available limestone almost chemically pure and a clay peculiarly adapted to the manufacture of the cement, while the Los Angeles petroleum provides a cheap and excellent fuel. These advantages

enable the company to manufacture its product at a minimum cost and to place it on the market for about three-fourths the price of foreign cements. The mixing, grinding, and burning of the crude materials is carried on under the constant direction and analysis of a chemist whose laboratory is at the works. The crude materials are first crushed and mixed by weight, then ground to an impalpably fine powder, then fed continuously at the rate of 3 tons hourly into a rotary kiln 75 feet long, in which they remain one and three-fourths hours. The low heat of the upper end of the kiln drives off the moisture from the raw mixture; the low red heat of the middle part decarbonizes the limestone; and the high heat of the lower end causes the caustic lime alumina and silica to unite and form Portland cement clinker—little nodules the size of beans and walnuts. After leaving the kiln the clinker is cooled and ground into the finished product. The materials enter the kiln as a mechanical mixture of limestone and clay and come from it a chemical compound of definite formulæ.

The character of the Colton cement is the same as that of all Portland cements. Analyzed it approximates some of the leading foreign brands, while the physical tests have generally shown it to be superior to the foreign brands in the local market both in the fineness of the powder and in its tensile strength.

Analyses of Portland cements.

Constituent.	Colton, American (E. Duryee, analyst).	White Bros., English (E. Duryee, analyst).	Alsens, German (W. MacClay, analyst).
	Per cent.	*Per cent.*	*Per cent.*
Silica (SiO_2)	22.060	23.567	24.90
Alumina (Al_2O_3)	9.310	10.020	11.22
Ferric oxide (Fe_2O_3)	3.090	3.080	
Magnesia (MgO)	0.900	1.067	0.38
Lime (CaO)	61.512	59.000	59.28
Sulphuric acid (SO_3)	1.200	1.400	0.86
Alkalies	1.761	2.100	0.50
Moisture and carbonic acid			2.16
Total	99.833	100.234	100.00

The following table comprises data from the report of Mr. J. W. Robinette, C. E., the cement tester, who sampled and tested 4,000 barrels of the product purchased by the San Gabriel Electric Company:

Results of tests of Colton Portland cement.

Length of time.	Number of tests.	Average tensile strength.	Fineness passed.	Average of 4,000 barrels.
		Pounds.	*Mesh.*	*Per cent.*
1 day	255	129	2,500	99.64
7 days	510	510	8,100	95.33
28 days	481	607	144,000	93.22

The extreme care taken to insure a good and uniform cement may be inferred from the fact that the raw mixture is every half hour subjected to chemical tests for the determination of the percentage of lime, which element is not permitted to vary either way more than 1 per cent from the standard. The mixture is ground so fine that only one-third of 1 per cent remains on a 50-mesh screen, 5 per cent on a 90-mesh screen, and 7 per cent on a 120-mesh screen. After it has been burned the clinker is spread in layers on a cooling and mixing floor, and the accumulated burn of several days is thoroughly mixed before it is ground. After the cement has been ground and again mixed in conveyers and elevators it is put into sacks holding 95 pounds each. A sample is taken from every tenth sack and numbered. These samples are tested, a record of the tests being kept and embodied in the reports which are mailed to the purchasers.

ACKNOWLEDGMENTS.

In the preparation of this report on the water systems of San Bernardino Valley, involving as it does numerous historical references, many authorities were consulted. The writer is particularly indebted to Mr. Kingsbury Sanborn, chief engineer of the Riverside Water Company, who rendered valuable assistance in the determination of the total output from the gravel beds above Colton and who assisted in many other ways, and to Mr. William Irving, who furnished nearly all of the data concerning the Gage canal and who assisted generally. Acknowledgments are also due to many other engineers familiar with local conditions.

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CHARLES D. WALCOTT, DIRECTOR

PRELIMINARY LIST

OF

DEEP BORINGS IN THE UNITED STATES

PART II

(NEBRASKA-WYOMING)

BY

N. H. DARTON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1902

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., November 27, 1901.

SIR: I have the honor to transmit herewith Part II of a preliminary list of deep borings in the United States (400 feet or more in depth), by Mr. N. H. Darton, with the request that it be published in the series of Water-Supply and Irrigation Papers. Part I is in type as Paper No. 57. It has been found necessary to divide the whole into two papers, because of the statutory limit of 100 pages for these papers.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

PRELIMINARY LIST OF DEEP BORINGS IN THE UNITED STATES.

PART II.—NEBRASKA-WYOMING.

By N. H. Darton.

INTRODUCTION.

The wells and borings reported in the paper are all more than 400 feet in depth. The information concerning them has been obtained partly from replies to circular letters sent to all parts of the United States and partly from geological reports and other published sources. Owing to the difficulty of obtaining replies to the circulars, to lack of knowledge on the part of correspondents, and to the incompleteness of published records, doubtless there are borings which have not been reported. In regions of oil and gas wells, where borings are numerous, the individual wells can not be listed here, but representative wells are given. References to logs or records of the wells, or extended descriptions of them, are given in footnotes, and after the list of wells in each State there is added a list of the principal publications relating to deep borings in that State.

The bearing of the information given in the columns of the lists probably is apparent, unless, perhaps, in the one headed "Height to which the water rises." In this column an entry such as "—45" indicates that the water rises to within 45 feet of the surface; "+45" indicates that it is a flowing well and has sufficient head to raise the water 45 feet above the surface in an open pipe 45 feet or more in height. The yield in gallons per minute usually is estimated. Depths and diameters often have been reported from memory, and different sources of publication sometimes give different figures. Most wells which are not stated to be "for oil," "for gas," "brine," "abandoned," etc., in the remarks column, or "not any" in the yield column, generally afford more or less water. Many of the gas and oil wells, active or abandoned, yield salt water.

NEBRASKA.

(Arranged by counties.)

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Hastings[1]	Adams	1,145			—40	Salt water at 940 feet.
Harrisburg	Banner	400-790				Several unsuccessful borings.
T. 34, R. 8, sec. —	Boyd	760	3	100	Flows.	
T. 33, R. 8, sec. 18	do	760	3	420	Flows.	
Kearney	Buffalo	2,460(?)				Unsuccessful.
T. 10, R. 13, sec. 34	Cass	480	3			Water at 30 feet.
Do	do	500	4			Water at 470 feet.
St. Helena[2]	Cedar	466		Many.	Flows.	Water at 400 feet.
T. 32, R. 33, sec. 23	do	400	2	30	Flows.	
T. 32, R. 23, sec. 24	do	448	2	30	Flows.	Water at 248 feet.
T. 31, R. 23, sec. 11	do	600	2		Flows.	Water at 340 feet.
T. 33, R. 13, sec. 35	do	600	2		Flows.	Water at 600 feet.
T. —, R. —, sec. —	do	602	2	25	Flows.	Water at 550 feet.
T. —, R. —, sec. 10	do	481	2		Flows.	
T. 32, R. 23, sec. —	do	445	2		Flows.	Water at 398 feet.
T. 6, R. 39, sec. 21	Chase	500	2			Water at 22 feet.
Cliff	Custer	400-485	3½-1½	Many.	No flow.	Several wells.
Chadron	Dawes	400, 1,100, and 1,800				Three wells; no water.
T. 31, R. 5, sec. 5	Dixon	407	2	60	Flows.	
T. 31, R. 6, sec. 20	do	484	3		Many.	Water at 18 feet; supply unlimited.
Omaha (Clark and Sixteenth streets)	Douglas	664		125	+52	Temp. 58°.
Omaha (Grant smelter).	do	1,044	10-6	800	+65	Flows at 650 and 800 feet also; temp. 55°.
Omaha (Thirty-second and O streets).	do	1,800		Many.	—70	
Omaha (Elmwood Park).	do	1,845			—50	
Omaha (Hanscom Park).	do	1,120		Many.	—138	
Omaha (Riverview Park).	do	1,065		600		Temp. 62°.
Omaha (Willow Spring).	do	1,700		Many.	+100	
Omaha (Exposition grounds).	do	1,115		Many.	Flows.	First water at 700 feet; temp. 60°.
Omaha (Seymour Park).	do	1,303		500	+35	
Omaha (Pickards)	do	1,383		70	Flows.	Temp. 62°; abandoned.
Omaha (Krug brewery).	do	1,310		Many.	—142	
Omaha (Power house, Nineteenth street).	do	840				
Omaha (Cortland Beach).	do	998	6-5		+40(?)	
Farm of G. E. Hawkins.	Gage	1,260	6		Flows.	
Beatrice	do	1,200		Few.	Flows.	
Farm of W. E. Robertson.	do	1,240	6		Flows.	Water at 50 feet.
Hyannis	Grant	+400				Two wells.
O'Neill	Holt	1,300				Unsuccessful.
Farm of E. Demerit	Hooker	1,200			Flows.	
Dannebrog[3]	Howard	1,011				Do.
T. 2, R. 2, sec. 4	Jefferson	500	4		+½	Seven borings for coal; strong salt water at 225-238 feet; temp. 70°.
T. 13, R. 35, sec. 5	Keith	525	6	500		Water at 7 feet.
T. 14, R. 41, sec. 2	do	407	3½	2		Water at 385 feet.
T. 12, R. 37, sec. 8	do					Water at 176 and 305 feet; 137 feet of water in well.
T. 9, R. 8, sec. 29	Kimball	460		Many.	No flow.	
T. 32, R. 6, sec. 16	Knox	656	8	Many.	Flows.	Water at 625 feet.
T. 33, R. 8, sec. 18	do	770	3		Flows.	Water at 740 feet.
T. 33, R. 3, sec. 13	do	504	2	90	Flows.	Water at 482 feet.
T. 32, R. 6, sec. 8	do	600	2	280	Flows.	Water at 435 feet.
T. 32, R. 6, sec. 16	do	656	8	2,500	Flows.	Water at 575 feet.
T. 32, R. 6, sec. 16	do	656	8	2,500	Flows.	Water at 600 feet.
T. 32, R. 6, sec. 16	do	630	8		Flows.	

[1] Record, U. S. Geol. Survey, Water-Supply and Irrigation Paper No. 12, pp. 37-38.
[2] Record, Am Assoc. Adv. Science, Proc., vol. 35, 1886, pp. 217-219.
[3] Record, U. S. Geol. Survey, Water-Supply and Irrigation Paper No. 12, p. 47.

NEBRASKA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
T. 32, R. 2, sec. 17	Knox	420		50		
Santee Agency Mission.[1]	do	603	2¼	20		
Lincoln (sanitarium).[2]	Lancaster	570				
Lincoln[3]	do	985			−100	Salt water at 244 and 544 feet.
Lincoln (Burlington Beach).	do	2,463		Many.	Flows.	Salt water.
Lincoln (public square).	do	1,050		Many.	Flows.	Salt water at 560 feet and 1,050 feet.
Tilden	Madison	400+	4		−90	
Norfolk	do	472			−100	
Brownville[4]	Nemaha	1,001				
Nebraska City	Otoe	448	4	¼	+6	Mineral water.
Do	do	1,000-1,200				Several deep wells in progress.
Do	do	570				Salt water.
Dubois	Pawnee	562	6			Unsuccessful.
McCook	Redwillow	400	8			Some water at 375 feet.
Falls City	Richardson	1,300				
Rulo (2 miles west)	do	1,370				Coal prospect.
Seward[5]	Seward	610			No flow.	Abandoned.
Gordon	Sheridan	580				Failure; water at 180-182 feet.
York[6]	York	590			+16	
Ericson	Wheeler	(?)				Failure.

[1] Record, 51st Cong., 1st sess., Senate Ex. Doc. No. 222, pl. op. p. 55.
[2] Descriptions, records, etc., U. S. Geol. Survey, Water-Supply and Irrigation Paper No. 12, pp. 28-30; Am. Assn. Av. Science, Proc., vol. 35, p. 218; Physical Geography and Geology of Nebraska (Aughey), 1880.
[3] Record, Am. Assoc. Adv. Science, Proc., vol. 35, p. 218.
[4] Am. Assoc. Adv. Science, Proc., vol. 35, pp. 217-219.
[5] Record, U. S. Geol. Survey, Water-Supply and Irrigation Paper No. 12, p. 31.
[6] Ibid., pp. 33-34.

PRINCIPAL PUBLICATIONS RELATING TO DEEP BORINGS IN NEBRASKA.

Underground Waters of a Portion of Southeastern Nebraska, by N. H. Darton, United States Geological Survey, Water-Supply and Irrigation Paper No. 12, 56 pages, maps, plates, Washington, 1898.

A Preliminary Report on the Geology and Water Resources of Nebraska west of the one hundred and third meridian, by N. H. Darton. United States Geological Survey, Eighteenth Annual Report, 1896-1897, part 4, pages 719-785, Washington, 1899.

NEVADA.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Battle Mountain[1]	Lander	800	6			Strong flow.
Do.[2]	do	650		58		Several flows at less depths.
Dalamar	Lincoln	800				Unsuccessful.
——[3]	Ormsby	400	6-7	5		Several wells.
Ely	White Pine	600		Several.		
Sierra Valley[4]	(?)	1,132	3	30		Hot water.
Vail Ranch	Churchill	400			No flow.	

[1] Nevada, Report Surveyor-General and State Land Register, 1891-92, p. 72.
[2] Ibid., 1889-90, p. 82.
[3] Ibid., 1891-92, p. 72.
[4] Ibid., 1889-90, p. 82.

NEW HAMPSHIRE.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Dover	Strafford	400	6	100	No flow.	
Concord	Merrimac	1,325	6	Few.	−16	Well abandoned; water at 935 feet.
Manchester	Hillsboro	630	8	Few.	No flow.	

NEW JERSEY.

Allenhurst [1]	Monmouth	530			Flows.	
Do	do	545			Flows.	
Asbury Park [2]	do	448	8	65½	Flows.	Good water; temp. 60°.
Do	do	800			Flows.	
Do	do	1,130-1,045	6	1,000	Flow.	Two wells.
Do.[3]	do	1,330			Flows.	
Atlantic City [4]	Atlantic	578	8		Flows.	Water at intervals from 328 to 554 feet.
Do	do	809	6		Flows.	
Do	do	1,150	8-6		+5	No water 960-1,120 feet.
Do	do	960	6-4½		Flows.	Pumps 200 gallons.
Do	do	554	8	50	Flows.	
Do	do	735	6-4½		Flows.	Do.
Do	do	720	6		Flows.	Pumps 250 gallons.
Do	do	780	6-4½	150	Flows.	
Do	do	763	8	Many.	Flows.	
Do	do					
Do	do	1,398	10-4½			No water at this depth. Several flows above.
Do	do	805	8-4½	40	Flows.	Pumps 125 gallons.
Do	do	843	6	100	Flows.	
Do	do	813	6	105	Flows.	Pumps 400 gallons; temp. 66°.
Do.[5]	do	1,400	10-4			No water at this depth. Several flows above.
Atlantic Highlands	Monmouth	480	4½	250	Flows.	
Avalon [6]	Cape May	925	10-4½	75	8	
Avon Inn [7]	Monmouth	430	3	52	Flows.	
Bayhead	Ocean	710			Flows.	
Do	do	885			Flows.	
Bayhead (1 mile north).[8]	do	813	4½-3	85	Flows.	
Barnegat Park [9]	do	670			Flows.	
Bayonne	Hudson	600		Few.		
Beach Haven [10]	Ocean	430	3	10	Flows.	
Do.[8]	do	575	8	125	Flows.	
Belmar [9]	Monmouth	445-480			Flow.	Four wells.
Do	do	640-660			Flow.	Two wells.
Berkeley Arms [11]	Ocean	475		60	To surface.	
Bernardsville	Somerset	621		3½		
Brigantine [12]	Atlantic	798	6	100	Flows.	
Brookdale [13]	Essex	712	4½	174		
Burlington		675				
Cape May Point [14]	Cape May	456				Unfinished.
Crab Island		520	3		Flows.	
Columbus [15]	Burlington	715				
Daretown [16]	Salem	405			−100	
Dealbeach	Monmouth	500-525	6		Flow.	Two wells.

[1] Record, etc., New Jersey Geol. Surv., Report for 1893, pp. 413-414.
[2] Record, New Jersey Geol. Surv., Reports for 1883, p. 20; 1884, p. 124; 1885, p. 129.
[3] Record, etc., New Jersey Geol. Surv., Report for 1895, pp. 72-74.
[4] Records, etc., of many wells at Atlantic City. New Jersey Geol. Surv., Reports for 1887, 1888, 1889, 1892, 1893, 1894, 1895, 1896, 1897, 1898, and 1899.
[5] Record, New Jersey Geol. Surv., Report for 1890, p. 90.
[6] Record, New Jersey Geol. Surv., Report 1898, pp. 78-82.
[7] Record, etc., New Jersey Geol. Surv., Report for 1885, p. 130.
[8] Record, etc., New Jersey Geol. Surv., Report for 1893, pp. 394-396; 1896, p. 152.
[9] Records, etc., New Jersey Geol. Surv., Report for 1896, p. 154.
[10] Record, etc., New Jersey Geol. Surv., Report for 1890, p. 266; 1893, pp. 394-396.
[11] Record, etc., New Jersey Geol. Surv., Report for 1884, p. 127; 1885, p. 133.
[12] Record, etc., New Jersey Geol. Surv., Report for 1895, pp. 77-79.
[13] Record, etc., New Jersey Geol. Surv., Report for 1897, pp. 227-229
[14] Record, etc., New Jersey Geol. Surv., Report for 1885, p. 140.
[15] Record, etc., New Jersey Geol. Surv., Report for 1892, pp. 305-306.
[16] Record, etc., New Jersey Geol. Surv., Report for 1897, pp. 250-253.

NEW JERSEY—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Farmingdale [1]	Monmouth	730				Water from 530 feet.
Flemington	Hunterdon	405		107	−161	
Fort Lee		1,000				Through trap into shale. No water.
Franklin [2]	Essex	400	8	125		
Greenwich [3]	Cumberland	690	4–2½			No water found.
Glassboro [4]	Gloucester	511				
Harrisonville [5]	do	402				
Harvey Cedars	Ocean	500	4	100	Flows.	
Do.[6]	do	500	4½	120	+6	
Hazlet [7]	Monmouth	577	8–4½			
Hightstown [8]	Mercer	428–500		Many.		
Hoboken [9]	Hudson	400				Bored in 1826. Rock at 40 feet
Holmdel [10]	Monmouth	601	8–4		Flows.	
Jamesburg [11]	Middlesex	481	8–6	52		
Jersey City (Limbeck's brewery).[12]	Hudson	776½	8	33		
Jersey City (Malone & Co.).	do	500		50		
Jersey City (Stock Yards).[13]	do	455	8–6½			
Jersey City (Communipaw).	do	500				Salt water.
Jersey City (Sugar Refinery).[12]	do	1,000	8–4	50		
Jersey City (Cox's brewery).[12]	do	400	5	Few.		
Jersey City (Dixon Co.).	do	1,205		22		
Jersey City (Colgate & Co.).	do	1,500		15		Rock 35–1,500 feet.
Jersey City (Hudson Canal Co.).	do	650		Few.		
Jersey City (Traction Co.).	do	2,200				No water.
Jersey City (Mehl & Co.).[14]	do	1,007		150		
Jersey City (Coal dock).[15]	do	450				Brackish water.
Jobstown [16]	Burlington	715				
Kearney	Union	600		50		
Lake Como [17]	Monmouth	535			Flows.	
Lakewood [18]	Ocean	475		3½	+17	
Do.[19]	do	600–625	6	100	+200	Several wells.
Loch Arbor		562			Flows.	
Longport [20]	Atlantic	803	6	180	Flows.	Temp. 66°.
Mantoloking	Ocean	790		25	+33	
Do.[21]	do	922		60	+42	
Moorestown [22]	Burlington	457				
Morristown (2 miles west).	Morris	438	6	2½	−60	
Mount Holly	Burlington	675				Impure water.
Montclair (Mount Prospect).	Essex	510	7½	45		Soft water.
Newark (Balentine's)	do	529		150		
Newark (Celluloid Co.).	do	827	10	200	No flow.	
Newark (Citizens' Gas Co.).	do	600		50		

[1] Record, etc., New Jersey Geol. Surv., Report for 1898, pp. 98–100.
[2] Record, etc., New Jersey Geol. Surv., Report for 1884, p. 127; 1885, p. 133.
[3] Record, etc., New Jersey Geol. Surv., Report for 1885, p. 131; 1894, pp. 190–193.
[4] Record, etc., New Jersey Geol. Surv., Report for 1894, pp. 407–409.
[5] Record, etc., New Jersey Geol. Surv., Report for 1896, pp. 126–127.
[6] Record, etc., New Jersey Geol. Surv., Report for 1896, pp. 166–168.
[7] Record, etc., New Jersey Geol. Surv., Report for 1897, pp. 247–248.
[8] Record, etc., New Jersey Geol. Surv., Report for 1894, pp. 200–201.
[9] Record, New Jersey Geol. Survey, Reports for 1879, p. 132; 1882, p. 139; 1885, p. 111.
[10] Ibid., Report for 1895, pp. 147–148.
[11] Ibid., Report for 1880, p. 165.
[12] Ibid., Reports for 1879, pp. 130–132; 1882, pp. 138–140; 1885, p. 118.
[13] Ibid., Reports for 1880, p. 172; 1882, p. 139; 1885, p. 111.
[14] Ibid., Report for 1898, p. 140.
[15] Ibid., Report for 1888, p. 77.
[16] Ibid., Report for 1897, pp. 247–248.
[17] Record, etc., New Jersey Geol. Surv., Report for 1894, p. 75.
[18] Record, etc., New Jersey Geol. Surv., Report for 1885, p. 131; 1884, p. 125; 1895, pp. 148–149.
[19] Record, etc., New Jersey Geol. Surv., Report for 1898, pp. 96–98; 1899, pp. 73–74.
[20] Record, etc., New Jersey Geol. Surv., Report for 1895, pp. 83–85.
[21] Record, etc., New Jersey Geol. Surv., Report for 1895, p. 77.
[22] Record, etc., New Jersey Geol. Surv., Report for 1893, pp. 413–414.

NEW JERSEY—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Newark	Essex	615	8	556		
Newark (Balentine's).[1]	do	450	8	200		
Newark (smelter)[2]	do	500	8	500		
New Brunswick[3]	Middlesex	455	1¼			
Do.[4]	do	480		Few.		Very hard water.
Do	do	976	8	7		Water at 300-350 feet.
North Spring Lake	Monmouth	705	6	100	Flows.	
Ocean Beach[5]	do	485	3	25	+34	
Do.[6]	do	480	3	50	Flows.	
Ocean Grove[6]	do	420	6	40	Flows.	Temp. 60°.
Do.[7]	do	1,134			Flows.	
Ocean City[8]	Cape May	800		140	Flows.	
Do.[9]	do	821	8	Many.	Flows.	
Do.[10]	do	760		Many.	Flows.	
Do	do	830	8-6	Many.	Flows.	
Passaic	Passaic	402	8	240	−28	
Do	do	558	8	112	−28	Water at 400 feet.
Do	do	1,000		Few.		
Paterson[11]	do	2,100	8-4	100		Water at 900 feet only.
Do	do	900		100		
Point Pleasant[12]	Ocean	806		45	Flows.	
Poplar		520			−30	
Reedy Island[13]		570		20	Flows.	
Sayreville[14]	Middlesex	976	8	7		Some water at 300 feet.
Seabright[15]	Monmouth	715	6-4½		−5	Water 260-300, 350-390, 685-715 feet.
Seagirt[16]		755	3	50	Flows.	Temp. 65°; water also at 570 and 694 feet.
Seaside Park[17]	Ocean	515		16	Flows.	Temp. 58°.
Sea Isle City[18]	Cape May	464			Flows.	
Do[19]	do	854	6	160	+14	
Secaucus[20]	Hudson	600	6	8	No flow.	Water from 200 to 250 feet.
Seven Islands[21]		408	6-3	70	Flows.	
Do		535		60	Flows	
Sewell	Gloucester	420	3			Water also at 72, 381, and 395 feet.
Smiths Landing[22]	Atlantic	715	6	100	−17	
South Beach Haven[19]	Ocean	425	8-6	10	+14	
Spring Lake	Monmouth	465-730			Flows.	
Telegraph Hill[23]		575				
Toms River[24]	Ocean	745				
Union	Union	500			Flow.	Ten wells.
Ventnor[25]	Atlantic	813	6		Flows.	
West Asbury Park[26]	Monmouth	508-558		150 each		Four wells.
Waverly	Union	450		Few.		
Wildwood	Cape May	655		300	Flows.	Temp. 63°.
Do[27]	do	1,244		10	Flows.	Temp. 67°; water at 625, 750, 843, and 1,185 feet.
Woodstown	Salem	776				

[1] Record, etc., New Jersey Geol. Surv., Reports for 1879, p. 126; 1882, p. 142; 1885, p. 115.
[2] Record, etc., New Jersey Geol. Surv., Report for 1879, p. 126; 1882, p. 142; 1885, p. 114.
[3] Record, etc., New Jersey Geol. Surv., Report for 1879, p. 133; 1882, p. 147; 1885, p. 113.
[4] Record, etc., New Jersey Geol. Surv., Report for 1887, p. 27.
[5] American Journal of Science, 3d series, vol. 30, p. 162.
[6] Record, etc., New Jersey Geol. Surv., Reports for 1884, p. 124; 1885, pp. 129-131.
[7] Record, etc., New Jersey Geol. Surv., Report for 1894, pp. 74-75.
[8] Record, etc., New Jersey Geol. Surv., Report for 1893, pp. 398-399.
[9] Record, etc., New Jersey Geol. Surv., Report for 1896, pp. 171-173.
[10] Record, etc., New Jersey Geol. Surv., Report for 1892, pp. 279-281.
[11] Record, etc., New Jersey Geol. Surv., Report for 1879, p. 128; 1882, p. 143; 1885, pp. 115, 117.
[12] Record, etc., New Jersey Geol. Surv., Report for 1895, pp. 76-77.
[13] Record, etc., New Jersey, Geol. Surv., Report for 1895, pp. 141-142; 1897, pp. 248-249.
[14] Ibid., Report for 1887, p. 27; 1888, p. 77.
[15] Ibid., Report for 1899, pp. 76-77.
[16] Ibid., Report for 1895, pp. 75-76.
[17] Ibid., Report for 1898, pp. 101-102.
[18] Ibid., Report for 1890, p. 268.
[19] Ibid., Report for 1896, pp. 175-177; 1886, p. 211; 1899, p. 109.
[20] Ibid., Report for 1879, p. 129; 1880, p. 172.
[21] Ibid., Report for 1885, p. 135; 1891, pp. 230-231.
[22] Ibid., Report for 1899, pp. 104-106.
[23] Ibid., Report for 1896, p. 153.
[24] Ibid., Report for 1893, pp. 399-400; 1894, pp. 159-180; 1898, pp. 102-103.
[25] Ibid., Report for 1898, pp. 76-78.
[26] Ibid., Report for 1899, pp. 74-76.
[27] Ibid., Report for 1897, pp. 247-248.

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New Jersey Geological Survey, Reports of the State Geologist for 1868, 1879, 1882 to 1885, 1887 to 1889, 1890, 1892 to 1899.

United States Geological Survey, Bulletin, No. 138, Artesian Well Prospects in the Atlantic Coastal Plain Region, by N. H. Darton, pp. 39–115, plates, Washington, 1896.

NEW MEXICO.

Location.	County.	Depth.	Diameter	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Deming	Grant	980	6	Many.	— 18	Never used.
Eddy [1]	Eddy	+600			No flow.	
Gallup	McKinley	600	10	Several.	-225	No water below 135 feet.
Guam	do	600	10			
Las Vegas	San Miguel	1,860	6	Several.	— 30	Strongly mineral water; abandoned.
Manuelito	McKinley	610	10	Few.		Unsatisfactory water.
Raton	Colfax	1,878	6	Few.	—300	Two wells; abandoned.
Do	do	1,872	6		—300	
Santa Fe	Sante Fe	1,115				

PUBLICATIONS RELATING TO DEEP BORINGS IN NEW MEXICO.

Report on New Mexico, by L. G. Carpenter, Fifty-first Congress, first session, Senate Ex. Doc., No. 222, pp. 233–241, Washington, 1890.

Report of P. H. Van Diest, on the Geological Conditions of Artesian Basins in Eastern Colorado and New Mexico, Fifty-first Congress, first session, Senate Ex. Doc., No. 222, pp. 233–241, Washington, 1890.

On the Occurrence of Artesian and Other Underground Waters in Texas, eastern New Mexico, and Indian Territory west of the ninety-seventh meridian, by Robert T. Hill. A Report on Irrigation, etc., by R. J. Hinton, Fifty-second Congress, first session, Senate Ex. Doc., No. 41, part 3, pp. 41–166, Washington, 1893.

NEW YORK.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Albany	Albany					City wells.
Alexander	Genesee					Salt well.
——[2]	Allegany	839–1,800				Important field of oil wells, embracing over 6,500 borings. Some 3,000 feet deep.
Attica [3]	Wyoming	1,960				Salt well.
Auburn [4]	Cayuga	3,570				Gas well.
Do	do	3,400?				
Aurora [5]	do	1,068				Salty water.
Baldwinsville	Onondaga	2,358	6½			Gas well.
Baldwinsville (1 mile south). [6]	do	2,250				Do.
Baldwinsville (1 mile north). [7]	do	2,795				Do.
Ballston	Saratoga	560			+30	Mineral water.

[1] Record, Report on Irrigation. Fifty-second Congress, first session, Senate Ex. Doc. No. 41, part 2, p. 16, Washington, 1893.
[2] Records, Am. Inst. Mining Engineers, Trans., vol. 16, pp. 930–934.
[3] Record, Report of Supt. Onondaga Salt Springs for 1888, pl. 2.
[4] Record, American Geologist, vol. 25, pp. 156–160.
[5] Record, Report of Supt. Onondaga Salt Springs for 1888, pl. 2.
[6] Record, American Geologist, vol. 25, pp. 150–152.
[7] Ibid., p. 154.

NEW YORK—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Barker	Niagara	2,175				Salt, oil, and gas.
Barren Island [1]	Queens	720	6	50	Flows.	Excellent water.
Do [2]	do	740			Flows.	
Batavia	Genesee					
Bath (1 mile south)	Steuben	2,050				Gas well.
Binghamton [3]	Broome	3,117				
Binghamton (north of).	do	2,000				
Bristol [4]	Ontaria	+750				Salt well.
Brockport	Monroe	2,000				For gas; unsuccessful.
Brooklyn borough (Calvary Cemetery.) [5]	Kings	582		70		Soft water.
Brooklyn borough (foot of Thirty-ninth and Fortieth streets).	do	1,503	8-6			Salt water.
Buffalo	Erie	490	6			Gas well.
Do. [6]	do	1,365	5¼			Do.
		516-525				Several gas wells.
Do	do	560				Gas well.
Burden	Columbia	900				
Cairo (3¼ miles southwest). [7]	Greene	2,200	5¼		−310	For oil or gas; abandoned.
Caledonia	Livingston	1,100	8-6¼		− 25	Salty, sulphurous water.
Do. [8]	do	760				Salt well.
Campbell [9]	Steuben	2,250				For oil or gas.
Canandaigua	Ontario					Several oil wells.
Canastota	Madison	648				Bitter brines.
Canisteo	Steuben	2,000				Several unsuccessful borings for gas.
Cardiff [8]	Onondaga	844				
Castile [8]	Wyoming	2,525				Salt well.
Cedarville	Onondaga	1,157				Do.
Charlotte Center [10]	Chautauqua	2,332				For oil; unsuccessful
Do. [11]	do	2,262				Do.
Chittenango [12]	Madison	3,026				Gas well.
Clifton Springs [8]	Ontario	710				Salt well.
Clyde	Wayne	450	6		−12	
Do. [13]	do	1,792				
Clymer (4 miles east) [14]	Chautauqua	1,975				Gas well.
Cohocton (near)	Steuben					For oil.
Carfu (2 miles west)	Genesee	1,208 1,248	8-6¼		−15 and −135	Several gas wells.
Curlerville [8]	Livingston	1,145				Salt well.
Dansville	do	1,800				
Dundee	Yates	2,000				Rock salt at 1,800 feet.
Do	do	1,200				
Eagleville	Madison	1,889				
East Aurora [8]	Erie	1,465 1,503				Salt wells.
East Buffalo	do	1,000-3,000				For gas; unsuccessful.
Eden Valley [8]	do	1,750				Salt well.
Fredonia [15]	Chatauqua	1,207				Much salty water; several gas wells in vicinity.
Fulton [16]	Oswego	1,656-2,050				Several gas wells.
Gardenville [17]	Erie	800				Salt well.
Gasport	Niagara	2,007				Gas at 1,086 feet.
Geneva	Ontario	550			Flows.	

[1] Record, N. J. Geol. Surv., Report 1896, pp. 155-156.
[2] Ibid., pp. 156 157.
[3] Record, Geol. Soc., of Am.., Bull., vol. 4, pp. 93-94.
[4] Record, Rept. Supt. Onondaga Salt Springs for 1888, pl. 2.
[5] Record, U. S. Geol. Surv., Bull. 138, p. 34.
[6] Record, Am. Inst. Mining Engineers, Trans., vol. 16, pp. 924-925.
[7] Record, Am. Inst., Mining Engineers, Trans., vol. 16, p. 956.
[8] Record, Report Supt. Onondaga Salt Springs for 1888, pl. 2; Report for 1885, p. 15.
[9] Record, Geol. Soc. Am., Bull., vol. 4, pp. 97-100.
[10] Record, Pa. 2d Geol. Surv., Rept., vol. I[6], p. 325.
[11] Ibid., pp. 325-326.
[12] Record, Geol. Soc. Am., Bull. vol. 4, p 101.
[13] Record, Am. Inst. Mining Engineers, Trans., vol. 16, p. 942.
[14] Record, Pa. 2d Geol. Surv., Rept., Vol. I[6], p. 228.
[15] Analysis, Am. Inst. Mining Engineers, Trans., vol. 16, pp. 918-923.
[16] Record, Geol. Soc. of Am., Bull., vol. 4, pp. 105-106.
[17] Record, Report Supt. Onondaga Salt Springs for 1888, pl. 2.

NEW YORK—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Getzville	Niagara	1,400				Several good gas wells.
Glen Springs	Schuyler	1,500				For oil; unsuccessful.
Gowanda [1]	Cattaraugus	1,700				Salt well.
Greenpoint [2]	Onondaga	1,600				
Greig	Lewis	700				Bored for oil.
Greigsville [3]	Livingston	1,138-1,145				Salt wells.
Hollis Station [4]	Queens	406				
Honeoye	Ontario	646				Gas at 610 feet; several gas wells in vicinity.
Honeoye Falls [5]	Monroe	1,500				Gas well.
Howard (one-half mile west).	Steuben	2,000				For oil or gas; unsuccessful.
Hudson	Columbia	602	6	1	-60	
Hornellsville	Steuben	1,500	6¼			Gas at 650, 940, and 1,200 feet.
Do	do	1,522	6¼			Gas well.
Illion [6]	Herkimer	1,135				Gas in small quantities at 800, 950, and 1,000 feet.
Ithaca	Tompkins	2,250 2,250	10-6¼ 8-5¼			Two dry salt wells.
Ithaca (one-fourth mile south).[7]	do	3,185	8-5¼			Gas well.
Jamestown [8]	Chatauqua	1,807				Unsuccessful boring for oil.
Jamesville [9]	Onondaga	1,040				Salt well.
Knowersville [10]	Albany	3,012				Gas at 497 feet only.
Knowersville (4½ miles north).[11]	do	2,200				For gas; unsuccessful.
Lakeville [12]	Livingston	1,053				Salt well.
Leicester	do	1,165				Do.
Leroy [13]	Genesee	878-1,003				Salt wells.
Limestone [14]	Cattaraugus	1,500	4¼			For gas or oil.
Liverpool	Onondaga	600-1,969				Salt wells.
Livonia [15]	Livingston	1,432	Shaft.			Salt mine.
Do	do	1,100				Salt well.
Lockport	Niagara					Do.
Ludlowville	Tompkins	1,821	8			Salt wells.
Middletown	Orange	2,010	10-8	80	Flows.	
Do	do	600	6		-60	Two wells.
Mohawk	Herkimer	420	6		-30	Sulphurous water, unfit for use.
Montfredys Mills	Onondaga	1,140				Salt well.
Morrisville [16]	Madison	1,889				Gas well.
Mount Morris [17]	Livingston	1,130-1,422				Several salt wells.
Naples	Ontario	1,650				Salt well.
Neversink (near)	Sullivan	1,400				Gas boring; abandoned.
New Dorp	Richmond	600				No water.
New Rochelle	Westchester	1,155	10		-10	
New York City, 10th and Washington sts.	New York	500	6	600	No flow.	
New York City, 11th and Greenwich sts.	do	1,047	8	10	No flow.	
New York City, 28th st., near Broadway.	do	500	8	100	No flow.	
New York City, 47th st. and 4th ave.	do	600	8	100	No flow.	

[1] Ibid.
[2] Ibid. for 1884, pp. 12-15; 1888, pl. 2.
[3] Ibid., 1888, pl. 2.
[4] Record, U. S. Geol. Surv., Bull. 138, pp. 30-31.
[5] Record, Pa. 2d Geol. Surv., Report, Vol. I[5], p. 326.
[6] Record, American Geologist, vol. 25, pp. 132-135.
[7] Record and analysis, Am. Inst. Mining Engineers, Trans., vol. 16, p. 941; Report Supt. Onondaga Salt Springs for 1888, pl. 2.
[8] Record, Pa. 2d Geol. Surv., Report, Vol. I[4], p. 126.
[9] Record, Report Supt. Onondaga Salt Springs for 1888, pl. 2.
[10] Record and analysis, Am. Inst. Mining Engineers, Trans., vol. 16, pp. 951-952.
[11] Am. Inst. Mining Engineers, Trans., vol. 16, pp. 953-954.
[12] Record, Report Supt. Onondaga Salt Springs for 1888, pl. 2.
[13] Ibid., Report for 1884, pp. 19-20.
[14] Record, Pa. 2d Geol. Surv., Report, Vol. II., p. 272.
[15] American Geologist, vol. 15, p. 379; N. Y. State Geologist Report, 1893, vol. 1, p. 13.
[16] Record, Geol. Soc. of Am., Bull., vol. 4, pp. 96-97; Report Supt. Onondaga Salt Springs for 1888, pl. 2.
[17] Record, Report Supt. Onondaga Salt Springs for 1888, pl. 2.

NEW YORK—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
New York City, 59th st. and 11th ave.	New York	700	8	100	No flow.	
New York City, 72d st. and 8th ave.	do	1,200	8	8	No flow.	
New York City, 59th st. and 5th ave.	do	500		80	No flow.	
New York City, 92d st. and 3d ave.	do	685	9	300	No flow.	
New York City, 145th st. and 8th ave.	do	605	10-8		No flow.	
New York City, Washington Building.	do	1,000			No flow.	
New York City, Manhattan Insurance Building.	do	1,056	8	75	No flow.	
New York City, Liberty and Nassau sts.	do	720		80	No flow.	
New York City, N. Y. Life Ins. Building.	do	500			No flow.	
New York City, Fulton Market.	do	626			No flow.	
New York City, Broadway and Bleecker st.	do	448	7	80	No flow.	
New York City, Lafayette and Barnard sts.	do	700	8	80	No flow.	
New York City, Boulevard and 72d st.	do	700		25		Hard water.
New York City, 146th st. and 8th ave.	New York	1,035	8	500	No flow.	
New York City, 99th st.	do	609	8		No flow.	Abandoned.
Do	do	1,505	8	11	No flow.	Do.
New York City, 67th st. near 3d ave.	do	1,504	8		−32	Do.
New York City, 67th st. near 2d ave.	do	1,502	8	50	−38	Do.
New York City, Morris and Greenwich sts.	do	625	8	40	No flow.	Do.
Do	do	700	8		No flow.	Do.
New York Mills [1]	Oneida	2,000				Gas at 500 feet.
Niskayuna	Schenectady	400	6	75	−20	
Norwich	Chenango	900				Small amount of gas.
Do. [2]	do	2,334				Do.
Nunda [3]	Livingston					
Olean [4]	Cattaraugus	1,230				Gas well.
Pearl Creek	Wyoming	1,182-1,194				Salt wells.
Pearl Creek (1 mile south).	do	1,241				Salt well.
Perry [5]	do	2,108				Heavy bed of salt.
Penn Yan [5]	Yates					Small supply of gas for several weeks.
Phoenix	Oswego	2,600				Gas well.
Piffard [6]	Livingston	961-1,141				Several salt wells.
Port Colborne [7]	Erie	770-1,500				Several small gas wells.
Port Jervis	Orange	1,400				Unsuccessful.
Richland	Oswego					Numerous gas wells
Rock City (near) [8]	Dutchess	1,471-1,546				Oil wells.
Rock Glen [3]	Wyoming	2,111				Salt well.
Rome [9]	Oneida	1,632				Gas wells.
Do. [10]	do	832				Gas well.
Saltvale [3]	Wyoming	1,436				Salt well.
Sandy Creek	Oswego	1,000-1,250				Numerous oil wells.
Do. [11]	do	1,145				Gas at 675, 765, and 7[illegible] feet.

[1] Am. Inst. Mining Engineers, Trans., vol. 16, pp. 958-959.
[2] Record, Geol. Soc. of Am., Bull., vol. 4, p. 95.
[3] Record, Report Supt. Onondaga Salt Springs for 1888, pl. 2.
[4] Am. Inst. Mining Engineers, Trans., vol. 16, pp. 939-940.
[5] Ibid.
[6] Record, Report Supt. Onondaga Salt Spring for 1884, pp. 20-21.
[7] Record, Am. Inst. Mining Engineers, Trans., vol. 17, p. 401.
[8] Record, Pa. 2d Geol. Surv. Report, vol. I[4], p. 100.
[9] Record, American Geologist, vol. 25, pp. 137-143.
[10] Ibid., p. 145.
[11] Record, Geol. Soc. Am., Bull., vol. 4, p. 107.

NEW YORK—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Saratoga Springs	Saratoga	400	6	3¼		
Do	do	1,006	2¼	2	+75	
Do	do	600	6	½	Flows.	
Do	do	440	6	½	+40	
Do	do	520	6	½	+40	
Do	do	425	6	½	−16	
Saratoga Springs	Saratoga	478?			+40	Mineral water.
Do	do	422			−16	
Shodack Landing	Rensselaer	1,000?				Salt well.
Seneca Falls	Seneca	3,560				Gas well.
Do	do	400-500			Flow.	Several salt wells in vicinity.
Do.[1]	do	1,500				Gas well.
Silver Springs[2]	Wyoming	2,254				Salt well.
Springfield[3]	Otsego	419		2	No flow.	
Syracuse (near)[4]	Onondaga	1,115-1,969				
Tivoli	Dutchess	400				
Tully[5]	Onondaga	974-1,472				Numerous salt wells.
Uniontown	Madison					Gas well.
Utica[6]	Oneida	860				Gas well.
Do.[7]	do	1,720				
Vernon[8]	do	1,968				Gas well.
Warsaw[9]	Wyoming	1,600-2,039				Numerous salt wells.
Watertown[10]	Jefferson	530				Small flow of gas at 253 feet.
Watkins	Schuyler	+2,100				Several salt wells.
Wellsville (4¼ miles southwest).[11]	Allegheny	1,177				Oil well.
West Bloomfield[12]	Ontario	500	5			Gas well.
Whitneys Point (near).	Broome	1,120				Salt well.
Willets Point	Queens	400				
Williamsville	Erie	Av. 875	5¼		No flow.	Three wells; two unsuccessful.
Wolcott[13]	Wayne	2,383				Gas well.
Woodhaven[14]	Queens	577				
Woodhull	Steuben	3,000			+50	Unsuccessful oil well; flow of water at 300 feet.
Wyoming[15]	Wyoming	1,321-1,530				Salt wells.
York[16]	Livingston	828				Salt well.

[1] Record, Am. Inst. Mining Engineers, Trans., vol. 16, p. 949.
[2] Record, Rept. Supt. Onondaga Salt Springs for 1888, pl. 2.
[3] Record, U. S. Geol. Surv., Bull. 138, p. 29.
[4] Record, Geol. Soc. Am., Bull., vol. 4, pp. 102-105; Am. Inst. Mining Engineers, Trans., vol. 16, p. 944; Rept. Supt. Onondaga Salt Springs for 1888, pl. 2; for 1884, pp. 15-18.
[5] Record, Geol. Soc. Am. Bull., vol. 4, p. 105; Rept. Supt. Onondaga Salt Springs for 1888, pl. 2.
[6] American Geologist, vol. 25, p. 137.
[7] Record, Geol. Soc. Am., Bull., vol. 4, p. 100.
[8] Record, Am. Geol. vol. 25, pp. 145-149.
[9] Record, Rept. Supt. Onondaga Salt Springs for 1888, pl. 2.
[10] Record, Geol. Soc. Am., Bull., vol. 4, p. 107.
[11] Record, Pa. 2d Geol. Surv., Ann. Rept., 1886, part 2, pp. 774-775.
[12] Am. Inst. of Mining Engineers, Trans., vol. 13, p. 542.
[13] Ibid., vol. 16, p. 943.
[14] Record, U. S. Geol. Surv., Bull. 138, pp. 31-32.
[15] Record, Rept. Supt. Onondaga Salt Springs for 1888, pl. 2.
[16] Ibid.

PRINCIPAL PUBLICATIONS RELATING TO DEEP BORINGS IN NEW YORK.

Annual Report of Superintendent of Onondaga Salt Springs for 1888, 26 pages, plates. Albany, 1889.

The Thickness of the Devonian and Silurian Rocks of Central New York, by C. S. Prosser, American Geological Society, Bulletin, vol. 4, pp. 91-118, Rochester, 1893.

United States Geological Survey, Bulletin No. 138, 232 pages, Washington, 1896.

Gas Well Sections in the Upper Mohawk Valley and Central New York, by C. S. Prosser, American Geologist, vol. 25, pp. 131-162. March, 1900.

Petroleum and Natural Gas in New York State, by C. A. Ashburner, American Institute of Mining Engineers, Transactions, vol. 16, pp. 906-953.

NORTH CAROLINA.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Charlotte	Mecklenberg	900	2			Dry.
Davidson	do	500				Dry below 80 feet.
Durham	Durham	1,037		18	No flow	
Gold Hill	Rowan	1,000			-20	Shaft sunk for gold.
Hammocks	New Hanover	400		8		Water at 100 feet.
Monroe	Union	720	6-5	28	To surface.	
Do	do	1,050	8-6	28	Near surface.	
North Wilkesboro	Wilkes	600	8	85		Uncompleted.
Sanford	Moore	515	6¼	45	-3	
Selma	Johnston					Two deep wells.
Walnut Cove	Stokes	1,050	2¼			Unsuccessful; bored for coal.
Do (1 mile south)	do	500				Good flow of mineral water.
Wilmington	New Hanover	495			Flows.	Saline water.
Do	do	1,144	12-6	200		Flows of brackish water at 379, 496, 574, 608, 734, and 989 feet; 200-gallon flow at 518 feet; granite. 1,109 feet to bottom.

PUBLICATIONS RELATING TO DEEP BORINGS IN NORTH CAROLINA.

Artesian Well Prospects in the Atlantic Coastal Plain Region, by N. H. Darton, U. S. Geological Survey, Bulletin No. 138, 232 pages, plates, Washington, 1896.

NORTH DAKOTA.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Bismarck [1]	Burleigh	1,315	8-4			No flow.
Devils Lake [2]	Ramsey	1,520	8-3	82	+46	Flow at 1,470 feet.
Dickinson	Stark	1,325				No flow.
Edgeley	Lamoure	1,354	6	500	+138	Water at 1,300 and 1,350 feet.
Ellendale [1]	Dickey	860			+138	
Do [1]	do	1,067	4¼-3¼	700	+260	Water at 1,042 feet.
Grafton [2]	Walsh	912	8	700		
Hamilton City [3]	Pembina	1,565	6	16¼	+60	
Jamestown (asylum). [3]	Stutsman	1,524	8-3¼	4	+161	
Jamestown [1]	do	1,476	6¼-3¼	460	+223	Water at 1,385 and 1,458 feet.
Mandan [1]	Morton	2,000	10-4	3		Water at 327 feet only.
Medora [1]	Billings	941	4	33	+34¼	
Oakes [1]	Dickey	977				Water at 790, 845, 870, and 937 feet.
Portland	Traill	560		175	Flows.	
Rutland [3]	Sargent	600	2			
Sims [1]	Morton	1,311				No flow.
Staples		514		25	+115	
Towers City [1]	Cass	716	6-4¼	20-25	+122	
Wimbleton [1]	Barnes	1,557		200	+184	

[1] U. S. Geol. Surv., 17th Ann. Rept., 1895-96, part 2, pp. 59-63.
[2] Record, 51st Congress, 1st session, Senate Ex. Doc. No. 222, pp. 107-108, Washington, 1890.
[3] 51st Congress, 1st session, Senate Ex. Doc. No. 222, p. 322, Washington, 1890.

PRINCIPAL PUBLICATIONS RELATING TO DEEP BORINGS IN NORTH DAKOTA.

Report of F. S. Underhill for North Dakota, Fifty-first Congress, first session, Senate Ex. Doc. No. 222, pp. 105-109, Washington, 1890.

Report on Irrigation, Fifty-second Congress, first session, Senate Ex. Doc. No. 41, part 2, pp. 66-72, 87-94, Washington, 1893.

Preliminary report on Artesian Waters of a portion of the Dakotas, by N. H. Darton, United States Geological Survey, Seventeenth Annual Report, 1895-96, part 2, pp. 609-694, Washington, 1896.

OHIO.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*		
Ada [1]	Hardin	1,384-1,820				Several wells for gas; some successful, others yield only flows of salt water.
Amanda Township	Allen	1,200	10-5½		-75	Salt water at 20 feet.
Akron [2]	Summit	2,250				
Do. [3]	do	2,450				Some gas at 172 feet.
Arcadia [4]	Hancock	1,365				Gas at 1,180 feet.
Arcanum [5]	Darke	+1,150				Gas prospects; small product.
Arlington [6]	Hancock	1,304				Some oil and gas at 1,304 feet. Abandoned.
Ashtabula [7]	Ashtabula	500				Gas from 250 to 500 feet. Strong brine at 400 and 500 feet.
Athens	Athens	±1,200				Oil and gas wells.
Bairdstown	Wood	1,058				Gas wells.
Bairdstown (1¼ miles north). [8]	do	1,154				Gas well.
Bairdstown (near) [9]	do	1,154				For gas. Abandoned.
Barnesville [10]	Belmont	2,700				Gas wells.
Beaverdam	Allen	1,309				For oil; salt water found. Abandoned.
Beaverdam (5 miles east). [11]	Hancock	1,288-1,290				Gas wells.
Belden (near)	Lorain					Many oil wells.
Bellaire [12]	Belmont	1,550, 2,700				Small gas wells.
Belle Center [13]	Logan	+1,310				Very small flow of gas.
Bellefontaine [14]	do	1,590				Do.
Bellevue [15]	Huron	1,700				For gas, unsuccessful.
Belpre [16]	Washington	+1,740				
Berea (2½ miles northeast). [17]	Cuyahoga	960-1,240				Several gas wells.
Birmingham [18]	Erie	2,250				Salt water only.
Bloomingville [19]	Hocking	628				Small flow of oil.
Do	do					Two borings.
Bloomdale [20]	Wood	1,115				Large flow of gas.
Bloomville [21]	Seneca	2,150				For oil unsuccessful.
Bluffton [22]	Allen	1,328				Unsuccessful.
Bowling Green [23]	Wood	±1,300				Gas well.
Do [24]	do	1,152				Large volume of gas.
Bradner [25]	do	1,244				Small flow of oil.
Brooklyn Village [26]	Cuyahoga	1,033				Several gas wells in vicinity.
Brownhelm [27]	Lorain	740				A little gas and oil.

[1] Ohio Geol. Surv., Report, 1888, vol. 6, p. 219; report for 1890, pp. 184-186.
[2] Record, Ohio Geol. Surv., Report, 1888, vol. 6, p. 319.
[3] Ibid., pp. 357-358.
[4] Ibid., p. 217.
[5] Ibid., pp. 272-273.
[6] Ibid., p. 218.
[7] Ibid., pp. 424-425.
[8] Ibid., pp. 229-232.
[9] Ibid., pp. 232-233.
[10] Ibid., Report, 1890, p. 254.
[11] Ibid., Report, 1888, vol. 6, pp. 215-216.
[12] Record, ibid, p. 406.
[13] Record, ibid, p. 267.
[14] Record, ibid, pp. 266-267.
[15] Ibid., pp. 214-215.
[16] Ibid., p. 401.
[17] Records, ibid, pp. 433-436.
[18] Ibid., pp. 346-347.
[19] Record, Ohio Geol. Surv., Report, 1888, vol. 6, pp. 393-394.
[20] Ibid., pp. 233-234.
[21] Ibid., p. 201.
[22] Ibid., p. 216.
[23] Ibid., pp. 156-159, pl., p. 112.
[24] Ibid., p. 160.
[25] Ibid., p. 207.
[26] Ibid., pp. 430-431.
[27] Ibid., pp. 437-438.

OHIO—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet	*Inches.*	*Gallons.*	*Feet.*	
Brownhelm [1]	Lorain	635				Some oil.
Brown Township	Vinton	1,000	10-5¼			Oil, gas, and salt water.
Bryan [2]	Williams	1,974-2,037				Gas and oil wells; yield small: salt water at 2,037 feet.
Buckeye (east of) [3]	Knox					Gas wells.
Bucyrus [4]	Crawford	840-2,264				For gas or oil; salt water flow at 780 feet.
Cadiz oil field [5]	Harrison					Fair flow of oil.
Cambridge [6]	Guernsey	1,090-2,000				Gas and oil wells; yield small.
Camden [7]	Preble	900				Gas well.
Canal Dover [8]	Tuscarawas	2,760				Little gas and salt water.
Cannonsburg [9]	Hancock	1,300				Several oil wells.
Canton [10]	Starke	2,220				For oil, but only salt water found.
Do	do	+3,135				
Cardington [11]	Morrow	±2,300				Gas; small flow.
Carey and vicinity [12]	Wyandot	1,326-1,500	5¼			Several gas wells; some yield large supply.
Carroll [13]	Fairfield	2,300				Unsuccessful.
Celina [14]	Mercer	1,147-1,168				Gas wells.
Chicago Junction [15]	Huron	1,250				
Circleville	Pickaway					
Cincinnati (vicinity)	Hamilton					Numerous oil or gas wells; unsuccessful.
Cleveland [16]	Cuyahoga	400-1,500				Several gas wells.
Cleveland (gas company) [17]	do	2,200				No product.
Cleveland (Euclid and Case avenues) [18]	do	1,125-1,735				Small flow of gas.
Cleveland (Rolling Mill) [19]	do	3,000				
Cleveland (Central avenue)	do	535		Many.	−100	Large supply of water.
Cleveland (Gordon Park) [20]	do	520				Abandoned.
Cleveland (2 miles east) [21]	do	508				For oil and coal, unsuccessful.
Clyde [22]	Sandusky	1,850				Unsuccessful.
Coldwater (3½ miles east)	Mercer	1,100	8-5¼		15?	
Columbus Grove [23]	Putnam	1,278				Gas at 740 feet; some oil at bottom.
Columbus [24]	Franklin	2,020				No gas or oil.
Columbus (State House) [25]	do	2,775	6-4		+5	Saline water below 675 feet; temp. 91°.
Conneaut [26]	Ashtabula	850				Small gas supply.
Do	do	+1,942				Much strong brine.
Coshocton [27]	Coshocton	2,108				
Do. [28]	do	1,280				Unsuccessful.
Do. [29]	do	3,100				Do.
Coventry Township	Summit					
Covington [30]	Miami					Small supply of gas
Crestline [31]	Richland	2,864				
Cridersville	Auglaize	1,227	8-5¾		−40	Oil and salt water.

[1] Record, Pa., 2d Geol. Surv., Report II, p. 282.
[2] Record, Ohio Geol. Surv., Report, 1888, vol. 6, pp. 247-249, 786.
[3] Ibid., pp. 340-343.
[4] Ibid., pp. 363-364.
[5] Ibid., Report, 1890, pp. 250-252.
[6] Ibid., Report, 1888, vol. 6, pp. 320, 377-378.
[7] Ibid., p. 285.
[8] Ibid., pp. 320, 369-370.
[9] Ibid., p. 217.
[10] Ibid., pp. 359-360.
[11] Ibid., pp. 283-284.
[12] Ibid., pp. 203-207.
[13] Ibid., p. 388.
[14] Record, Ohio Geol. Surv., Report, 1888, vol. 6, pp. 259-260.
[15] Ibid., pp. 350-351.
[16] Ibid., pp. 429-430.
[17] Ibid., p. 430.
[18] Geol. Soc. Am., Bull., vol. 8, p. 10.
[19] Record, Mich. Geol. Surv., Report, 1881-1883, vol. 5, part 2, p. 73; Ohio Geol. Surv., Report, vol. 1, pp. 352-355; Ohio Geol. Surv., Report, 1888, vol. 6, pp. 351-355.
[20] Geol. Soc. Am., Bull., vol. 8, p. 10.
[21] Economic Geology of Ill., vol. 3, pp. 195-6.
[22] Ohio Geol. Surv., Report, 1888, vol. 6, p. 214.
[23] Ibid., p. 242.
[24] Record, ibid., pp. 281-283.
[25] Record, ibid., pp. 106-108; Am. Journal Science, 2d series, vol. 27, p. 276.
[26] Ohio Geol. Surv., Report, 1888, vol. 6, pp. 422-423.
[27] Record, ibid., p. 324.
[28] Ibid., p. 368.
[29] Ibid., p. 357; Report for 1890, pp. 245-246.
[30] Ibid., p. 274.
[31] Record, Ohio Geol. Surv., Report, 1888, vol. 6, pp. 303-304.

OHIO—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Dayton [1]	Montgomery	870				Some shale gas.
Do. [2]	do	2,440			200	
Defiance	Defiance	1,687				Salt water only.
De Graff [3]	Logan	1,356				Some oil and gas.
De Graff (1 mile west)	do	1,300	8-5½			
Delaware [4]	Delaware	2,130				Unsuccessful.
Delphos [5]	Allen	1,250				Do.
Delphos (Kill farm) [6]	do	1,218				Oil well.
Delta [7]	Fulton	2,150				Unsuccessful.
Deshler [8]	Henry	1,600				Only small flow of gas.
Dexter (near)	Noble					
Dresden [9]	Muskingum	2,525				
Do. [10]	do	+1,000				Unsuccessful.
Duchouquet	Auglaize					Two wells of moderate flow.
Dudley	Noble					
Dunkirk [11]	Hardin	1,865			—445	For gas; only salt water found.
Dunkirk [12]	do	1,370				Large flow of oil.
Eagle Mills	Vinton	600				Salt water.
Eaglesport [13]	Morgan	1,134				Salt water; abandoned.
Do	do	1,152	8-6			Oil rises to 40 feet.
East Liverpool [14]	Columbiana	425-450				
East Liverpool (on Dry Run). [15]	do	±3,000				Several gas wells.
East Liverpool (Knowles well).	do	2,954				Dry.
Eaton [16]	Preble	1,170-1,375				Several wells; unsuccessful.
Elnore [17]	Ottawa	+1,250				Two oil wells.
Elyria [18]	Lorain	987				Small gas supply and heavy flow of salt and sulphur water.
Felicity [19]	Clermont	400				Gas well.
Findlay [20]	Hancock	1,116-1,334				Many gas wells; some oil in several wells.
Do. [21]	do	1,648				Gas well; oil at 1,092 feet; salt water at 1,581 feet.
Findlay (1 mile northwest). [22]	do	1,334				Unsuccessful.
Flushing (1 mile northeast). [23]	Belmont	1,680				Salt water only.
Forest [24]	Hardin	1,470				Unsuccessful.
Forest (3 miles southwest).	do	480		Many.	Flows.	White sulphur water.
Fort Jennings	Putnam	1,425	8		—25	Salt water.
Fort Recovery [25]	Mercer	1,052				Gas for several months.
Fostoria [26]	Seneca	1,136-1,775				Several gas wells.
Fremont and vicinity. [27]	Sandusky	1,300-1,500				Do.
Do. [28]	do	568				Gas well.
Gallipolis [29]	Gallia	2,910				For oil: unsuccessful.
Geneva [30]	Ashtabula	850-1,375				Two wells; fair flow of gas; numerous other wells in the county.
Genoa [31]	Ottawa	1,308				Small flow of oil and gas.
Greenville [32]	Darke	1,200-1,700				Several borings for gas; unsuccessful.

[1] Record, Ohio Geol. Surv., Report, 1888, vol. 6, p. 288.
[2] Ibid., p. 286.
[3] Ibid., p. 268.
[4] Ibid., p. 270.
[5] Ibid., p. 240.
[6] Ibid., Report 1890, p. 217.
[7] Ibid., Report 1888, vol. 6, pp. 244-245.
[8] Ibid., p. 253.
[9] Ibid., Report 1890, p. 246.
[10] Ibid., Report 1888, vol. 6, p. 376.
[11] Ibid., p. 223.
[12] Ibid., Report 1890, p. 186.
[13] Ibid., Report 1888, vol. 6, pp. 389-390.
[14] Ibid., pp. 331-334.
[15] Ibid., pp. 322-323.
[16] Ibid., pp. 108, 284.
[17] Ibid., pp. 211-212.
[18] Ibid., pp. 347-348.
[19] Ibid., p. 301.
[20] Ibid., pp. 122-133, 146; Report for 1890, p. 125.
[21] Ibid., Report 1888, vol. 6, pp. 111-117.
[22] Ibid., pp. 131-132.
[23] Ibid., Report 1890, pp. 253-254.
[24] Ibid., Report 1888, vol. 6, p. 223.
[25] Ibid., pp. 263-264.
[26] Ibid., pp. 192-193, 146, 234.
[27] Ibid., pp. 183-189.
[28] Ibid., p. 188.
[29] Record, Pa. 2d Geol. Surv., Reports, vol. I[6], p. 335.
[30] Record, Ohio Geol. Surv., Report, 1888, vol. 6, pp. 425-426.
[31] Ibid., p. 213.
[32] Ibid., pp. 271-272.

OHIO—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Hamden	Vinton	780				Nothing but salt water.
Hamilton [1]	Butler	550-700				Gas wells; small flow.
Hammansburg [2]	Wood	1,194				Small flow of oil.
Harrisburg [3]	Franklin	405	6	Many.	Flows.	
Haskins	Wood					Oil well.
Henry Township [4]	do	1,125-1,150				Gas wells; some oil.
Do. [5]	do	1,212-1,295				Oil.
Hicksville [6]	Defiance	1,710				Salt water; some oil.
Hillsboro [7]	Highland	1,750				Good water at 1,750 feet.
Huntsville	Logan	1,460				Gas well.
Independence [8]	Cuyahoga	1,800				Several borings for oil; no product.
Ironton [9]	Lawrence	3,600				Unsuccessful.
Island Run [10]	Columbiana	600				
Jackson [11]	Jackson	1,600				Small flow of gas.
Jamestown	Greene	1,500				Salt water only.
Jerry City [12]	Wood	1,155				Two wells; one with fair supply of oil.
Joy [13]	Morgan	1,240				Only small flow of gas. Two wells; much salt water.
Kalida (1 mile north). [14]	Putnam	1,316				Bored for oil; salt water found.
Kenton [15]	Hardin	1,600				Unsuccessful.
Do	do					Do.
Kimbolton [16]	Guernsey	1,087				Do.
Do	do					Some gas.
Lacarne [17]	Ottawa	1,700				Much water.
Lafayette [18]	Madison					Unsuccessful.
Lancaster [19]	Fairfield	1,030				
Do. [20]	do	1,940-2,020	4¼-5¼			Several gas wells.
Lebanon [21]	Warren	700 and 1,390				Small flow of gas; much salt water.
Leipsic [22]	Putnam	1,456				Some oil and gas and great volume of salt water.
Lima [23]	Allen	1,200-1,400				Numerous oil wells here and in county; much salt water found.
Lindsey [24]	Sandusky	1,241-1,300	4			Three oil and gas wells; also flow; salt water in large quantities.
Lisbon [25]	Columbiana	1,582				
Little Sandusky	Wyandot	1,450	8-5¼		−40	Salt water at 25 feet.
Logan [26]	Hocking	625-689				Several wells; some oil, water, and gas.
Do	do	1,002				Some oil.
London [27]	Madison	1,585				Several wells for oil or gas.
Lorain [28]	Lorain	+600			−50	Mineral water; some gas.
Lone Star	Vinton	1,100				Salt water; some oil.
McArthur	Vinton	900-1,000				Fresh and salt waters.
McComb [29]	Hancock	1,455				Gas well with salt water.

[1] Record, Ohio Geol. Surv., Report, 1888, vol. 6, pp. 292-293.
[2] Record, ibid., p. 237.
[3] Analysis, U. S. Geol. Surv., 19th Ann. Rept., 1897-1898, part 1, p. 6614.
[4] Record, Ohio Geol. Surv., Report, 1888, vol. 6, pp. 237-238.
[5] Record, Pa. 2d. Geol. Surv., Ann. Report for 1886, part 2, p. 786.
[6] Record, Ohio Geol. Surv., Report, 1888, vol. 6, pp 250-251.
[7] Analysis, ibid., p 297.
[8] Ibid., p. 431.
[9] Record, ibid., pp. 304-306, 319
[10] Record, Pa. 2d Geol. Surv, Ann. Report, 1886, part 2, pp. 784-785.
[11] Ohio Geol. Surv., Report, 1888, vol. 6, pp. 319-394.
[12] Ibid., p. 233.
[13] Ibid., p. 390.
[14] Record, ibid., p. 243.
[15] Ibid., p. 220.
[16] Ibid., pp. 380-381.
[17] Ibid., p 213.
[18] Ibid., p. 219.
[19] Record, Ohio Geol. Surv. Report, 1886, vol. 6, p. 318.
[20] Ibid., pp. 382-388, 783.
[21] Ibid., pp. 295-296.
[22] Ibid., p. 242.
[23] Ibid, pp. 165-168.
[24] Ibid., pp. 213, 788-789.
[25] Ibid., p. 322.
[26] Ibid., pp. 318, 392-393.
[27] Ibid., pp. 280-281.
[28] Ibid, pp. 438-439.
[29] Ibid., p. 219.

OHIO—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
McConnellsville	Morgan	+3,000				For oil or gas; unsuccessful.
Do	do	1,330	7½-5½			Gas and salt water.
McCuneville[1]	Perry	1,368				Several wells; bored for salt water; some found.
Macksburg[2]	Washington	400-1,700				Large oil field about here.
Do.[3]	do	2,100				Numerous successful wells; gas also found.
Do.[4]	do	2,500				Oil and gas well.
Madison Township	Vinton	1,017	10-5½			Very little oil and salt water.
Magnetic Springs[5]	Union	1,600				Salt well.
Malta[6]	Morgan					Large flow of gas from several wells for oil or salt.
Mansfield[7]	Richland	2,005-2,415				Two borings for gas; unsuccessful.
Do.[8]	do	3,594	5-4			Unsuccessful.
Marietta[9]	Washington	1,740-2,940				Oil well.
Marietta (4 miles below).[10]	do	1,440				Gas well.
Marietta (near)[11]	do	3,015				Much salt water at 1,790 feet.
Marion[12]	Marion	1,790				Abandoned.
Martins Ferry[13]	Belmont	2,300				
Marion Township[14]	Hancock					Gas well.
Marysville[15]	Union	1,743				For gas or oil; found only water at 300 feet.
Massillon[16]	Stark	655-1,820				Nothing but salt water.
Do.[17]	do	671				Some oil; also salt water.
Do.[17]	do	2,547				Gas at 655 feet, shut out by salt water.
Medina[17]	Medina	917				Small flow of gas.
Miamisburg[18]	Montgomery	800-1,200				Two gas wells.
Middleport	Meigs	360-1,250	3 and 4	Av. 25		Great number of salt-water wells in county.
Do	do	1,500				Small amount of oil from 120-1,500 feet.
Middletown[19]	Butler	1,060				Some gas and salt water.
Milan[20]	Erie	2,000				For oil or gas; only salt water found.
Millersburg[21]	Holmes	2,100				
Millersburg (four miles from).	do	900-1,000				Gas and oil well.
Millers Station[22]	Guernsey	430				Salt well.
Monroeville[23]	Huron					Small flow of gas only.
Mount Blanchard[24]	Hancock					Moderate flow of oil and gas.
Mount Orab	Brown	800-1,200	5½			Gas wells.
Mount Vernon[25]	Knox	1,370, 1,707, 2,600				Three wells; unsuccessful.
Do.[26]	do	3,200	4½		—100	Gas well; water at 1,725 and 1,765 feet.
Do	do	2,135				Unsuccessful.

[1] Ibid., pp. 388-389.
[2] Ohio Geol. Surv., Report, 1888, vol. 6, pp. 450-464.
[3] Ibid., p. 453.
[4] Record, Pa. 2d Geol. Surv., Reports, Vol. I[5], pp. 333-334.
[5] Record, Ohio Geol. Surv., Report, 1888, vol. 6, p. 269.
[6] Ibid., p. 389.
[7] Ibid., pp. 318, 365-366.
[8] Ibid., Report 1890, p. 245.
[9] Ibid., Report 1888, vol. 6, pp. 368-410.
[10] Record, W. Va. Geol. Surv., Reports, vol. 1, p. 288.
[11] Ibid., pp. 286-287.
[12] Record, Ohio Geol. Surv., Reports, 1888, vol. 6, pp. 201-202.
[13] Ibid., pp. 404-406.
[14] Ibid., p. 236.
[15] Record, Ohio Geol. Surv., Report, 1888, vol. 6, pp. 269-270.
[16] Ibid., pp. 320, 361.
[17] Ibid., p. 360.
[18] Ibid., pp 288-289.
[19] Ibid., pp. 294-295.
[20] Ibid., p. 346.
[21] Ibid., pp. 367-368.
[22] Ibid., pp. 654-655.
[23] Ibid., pp. 439-440.
[24] Ohio Geol. Surv., Report, 1888, vol. 6, p. 218.
[25] Record, ibid., pp. 217, 266-267.
[26] Ibid., Report for 1890, pp. 244-245.

OHIO—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Napoleon [1]	Henry	1,889			+3	For gas; salt water at 1,889 feet.
Nelsonville [2]	Athens	570-950				Many salt wells; one small gas well.
Nevada [3]	Wyandot	2,000				Nothing but salt water.
Newark [4]	Licking	1,449-2,385				Several gas wells; small flows.
Newburg [5]	Cuyahoga	3,000	5½			Some gas; much salt water.
New Carlisle [6]	Clark	1,080				For gas; unsuccessful.
New Lisbon [7]	Columbiana	1,350-1,370				Gas wells.
New London [8]	Huron	998-1,030				Three wells; nothing found except salt water.
New Vienna [9]	Clinton	1,785				Salt water at 1,785 feet.
Niles [10]	Trumbull	780-900				Two borings for gas; unsuccessful.
North Baltimore [11]	Wood	1,104½-1,295				Two gas and oil wells.
Do. [12]	do	1,190				
North Bend	Hamilton	1,350	5	200	+30	Good water.
Norwalk [13]	Huron	2,304				
Do	do	2,725	5½			For oil or gas; unsuccessful.
Oak Harbor [14]		1,326-1,335				Three gas wells.
Oberlin	Ottawa	700				For oil or gas; unsuccessful.
Osborn	Greene	990				Unsuccessful.
Ottawa [15]	Putnam	1,314-1,365				Two oil and gas wells; small product; much salt water.
Oxford [16]	Butler	1,365				Shale gas and sulphur water only.
Painesville [17]	Lake	700-1,390				Several gas wells.
Patterson (2 miles south of). [18]	Hardin	1,330				Gas at 835 feet; large flow of water; unsuccessful.
Patterson (2 miles west of). [19]	do	1,300				Large flow of gas; also large flow of water.
Perrysburg [20]	Wood	+1,600				Several gas wells.
Piketon	Pike					
Pike Township [21]	Clarke	1,380				For gas; unsuccessful.
Piqua [22]	Miami	1,673				Do.
Plain City [23]	Madison	1,530-2,000	8		+13	Two wells; large flows of fine water from 350, 600, and 900 feet.
Plymouth [24]	Richmond	742				
Do. [25]	do	3,020				Salt and sulphur water at 850 feet.
Pomeroy	Meigs	1,550		20	−500	Salt well; some oil and gas.
Do	do	1,100				Several salt wells; flowed originally.
Do. [26]	do	767				
Pemberville	Wood					Unsuccessful.
Portage (vicinity) [27]	do	1,177				Do.

[1] Record, Ohio Geol. Surv., Report 1888, vol. 6, pp. 252-253.
[2] Ibid., p. 398.
[3] Ibid., p. 203.
[4] Ibid., pp. 317, 370-372.
[5] Record, Mich. Geol. Surv., 1881-1893, p. 73; Ohio Geol. Surv., Report, 1888, vol. 6, pp. 351-355; Ohio Geol. Surv., Report, vol. 1, pp. 352-355.
[6] Ohio Geol. Surv., Report, 1888, vol. 6, p. 280.
[7] Record, Ohio Geol. Surv., Report, vol. 6, 1888, p. 404.
[8] Ibid., pp. 440, 348-350.
[9] Ibid., pp. 296-297.
[10] Ibid., p. 401.
[11] Ibid., pp. 228 229; Pa. 2d Geol. Surv., Report for 1886, p. 786.
[12] Record, Ohio Geol. Surv., Report, 1888, vol. 6, p. 228.
[13] Ibid., pp. 440-441.
[14] Ibid., pp. 210-211.
[15] Ibid., p. 241.
[16] Ibid., p. 294.
[17] Ibid., pp. 427-428.
[18] Record, Ohio Geol. Surv., Report, 1888, vol. 6, pp. 221-222.
[19] Ibid., p. 222.
[20] Ibid., pp. 225, 788.
[21] Ibid., p. 280.
[22] Ibid., p. 273.
[23] Ibid., Report 1890, p. 246; U. S. Geol. Surv., 19th Annual Report, 1897-98, p. 663.
[24] Record, Ohio Geol. Surv., Report, 1888, vol. 6, p. 315.
[25] Ibid., pp. 302-303.
[26] Ibid., p. 397.
[27] Ohio Geol. Surv., Report 1888, vol. 6, pp. 164-165, 228.

OHIO—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Portage (vicinity) [1]	Wood	1,134				Unsuccessful.
Do.[1]	do					Large flow of gas.
Port Clinton [2]	Ottawa	+1,660				No product.
Portsmouth [3]	Scioto	2,000				No product, but salt water at 1,000 feet.
Prospect [4]	Marion	1,650				No product.
Quaker City [5]	Guernsey	1,347				Gas well.
Do	do	1,352				
Radcliff	Vinton	700 or 800				Water and gas.
Rarden	Scioto	1,710	10		--510	Water.
Rawson [6]	Hancock	1,337				For gas or oil; found salt water only.
Richland Furnace	Vinton					Gas well.
Ripley	Brown					No product.
Risingsun	Wood					Only small flow of oil.
Rockport [7]	Cuyahoga	527-1,335				Two gas wells; small flows.
Rutland Township	Meigs	1,560		10-25	—500	Salt water only.
Sabina	Clinton					
St. Henry [8]	Mercer	1,160-1,183				Gas well.
St. Marys [9]	Auglaize	1,230				Salt water only.
Do.[10]	do	1,132 1,225				Several oil wells.
Do.[10]	do	1,092 1,138				Several gas wells; large flows.
St. Paris [11]	Champaign	+1,000				Two unsuccessful borings.
Salem [12]	Columbiana	800-810+				Do.
Do	do	2,930				Unproductive.
Salem Township [13]	Wyandot	1,323				Small flow of oil.
Sandusky [14]	Erie	2,260				Some oil, gas, and salt water.
Saline Township [15]	Jefferson	1,105				Unproductive.
Sardis (SW of) [16]	Monroe	1,815				Oil well.
Sciotoville	Scioto	800				Unsuccessful.
Sevenmile	Butler	1,220	8		--6	Salt water and some gas.
Sheffield [17]	Lorain	720				Bored for oil; some gas found; unsuccessful.
Shelby [18]	Richland	1,480-1,796				Small flow of gas: 2 wells.
Sidney [19]	Shelby	1,205-1,250				Several gas wells; much salt water at 1,445 feet.
Somerset [20]	Perry	2,850			—400	Salt water at 2,850 feet.
South Kingsville [21]	Ashtabula	1,200				Gas well; some oil.
South Olive	Noble					Unproductive.
South Toledo [22]	Lucas	+1,012				Do.
Springfield [23]	Clarke	1,140-1,200				Several wells; unsuccessful.
Spring Valley [24]	Greene	1,500				Unsuccessful.
Steubenville [25]	Jefferson	1,290				Transient gas supply.
Do.[26]	do	2,519				
Stuartsville Township.[27]	Hancock	450				Oil wells.
Stryker	Williams	860				Mineral water at 230 feet.
Sunbury [28]	Delaware	2,530				
Tiffin [29]	Seneca	1,467-1,494				Several wells; large flow of gas; some oil.

[1] Ohio Geol. Surv., Report 1888, vol. 6, pp. 164-165, 228.
[2] Ibid., p. 212.
[3] Ibid., p. 395.
[4] Analysis, ibid., pp. 270-271.
[5] Record, ibid., pp. 324, 381-382.
[6] Ibid., p. 217.
[7] Record, Ohio Geol. Surv., Report 1888, vol. 6, pp. 432-434.
[8] Ibid., pp. 260-262.
[9] Ibid., pp. 255-258.
[10] Ibid., pp. 255-258.
[11] Ibid., pp. 276-277.
[12] Ibid., pp. 403-404, 452.
[13] Record, Pa. 2d Geol. Surv., Ann. Report for 1886, part 2, pp. 785-786.
[14] Record, Michigan Geol. Surv., 1881 1893, p. 83; Ohio Geol. Surv., Report, 1888, vol. 6, pp. 194-196.
[15] Record, Pa 2d Geol. Surv., Report II, p. 282.
[16] Record, W Va. Geol Surv., Reports, vol. 1, pp. 356-357.
[17] Record, Ohio Geol. Surv., Report, 1888, vol. 6, p. 437.
[18] Ibid., pp. 316, 364-365.
[19] Ibid., pp. 264-266.
[20] Ibid., Report 1890, p. 247.
[21] Ibid., 1888, vol 6, pp. 423-424.
[22] Ibid., p. 225.
[23] Ibid., pp. 278-280.
[24] Ibid., p. 291.
[25] Ibid., pp. 336-337.
[26] Record, Pa. 2d Geol. Surv., Ann. Report for 1886, part 2, p. 784.
[27] Ohio Geol. Surv., Report, 1890, pp. 219-220.
[28] Ibid., 1888, vol. 6, p. 283.
[29] Record, ibid., pp. 197-201.

OHIO—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Tiffin (vicinity of)[1]	Seneca	1,505-1,753				Several borings; all unsuccessful.
Tinney (south of)	Sandusky	1,220	8-5¼		—10	Gas, oil, and salt water.
Tippecanoe[2]	Miami	1,025				Small flow of gas.
Toledo[3]	Lucas	1,425				Several borings for gas and oil; unsuccessful.
Tontogany (2½ miles southeast).	Wood	1,425	8-5¼		—30	Some salt water, oil, and gas.
Toronto (4 miles west).[4]	Jefferson	1,455				For oil; unsuccessful.
Troy[5]	Miami	1,170				Some gas at 510, 680, and 880 feet.
Uniopolis	Auglaize					Very small flow of gas; abandoned.
Upper Sandusky[6]	Wyandot	1,340-1,347½				Two borings for oil or gas; unsuccessful.
Urbana[7]	Champaign	1,307-1,350				Very small showing of gas.
Vanlue[8]	Hancock	1,294				Small flow of gas.
Vanwert[9]	Vanwert	1,240				Very small flow of gas.
Vinton Township[10]	Vinton	490-1,057	10-5¼			Gas, oil, and salt water.
Wakeman	Huron	3,000				For oil; found salt water only at 1,950 feet.
Wapakoneta[11]	Auglaize	1,600				For oil or gas; salt water only.
Washington[12]	Fayette	1,850				For gas or oil; found salt water only
Waterville[13]	Lucas	1,153				Small flow of gas.
Wauseon[14]	Fulton	+2,158				Oil at 2,158 feet.
Wellington[15]	Lorain	1,030-1,050				Several small gas wells.
Westerville[16]	Franklin	+2,300				
Westminster[17]	Allen	1,400				For oil or gas; unsuccessful.
West Newton[18]	do	1,440				
Weston[19]	Wood	1,575				Oil, gas, and sulphur water.
Whartonsburg[20]		1,427				For oil or gas; unsuccessful.
Williamsburg	Clermont	600	6			Small flow of gas.
Do	do	660	6			Unsuccessful.
Willoughby[21]	Lake					Several small gas wells.
Wilmington[22]						
Woodville[23]	Sandusky	1,460				For oil or gas; only salt water found.
Wooster[24]	Wayne	1,805-2,000				Three borings for oil or gas; unsuccessful.
Xenia[25]	Greene	1,200				For oil or gas; unsuccessful.
Youngstown[26]	Mahoning	2,480				For gas or oil; unsuccessful.
Zanesville[27]	Muskingum	1,098-2,019				Three wells; some oil.

[1] Record, Ohio Geol. Surv., Report 1890, pp. 784-785.
[2] Ohio Geol. Surv., Report, 1888, vol. 6, p. 274.
[3] Record, ibid., pp. 208-209; Michigan Geol. Surv., 1881-1893, p. 85.
[4] Pennsylvania 2d Geol. Surv., Report I[5], p. 236.
[5] Ohio Geol. Surv. Report, 1888, vol. 6, p. 274.
[6] Ibid., p. 202.
[7] Record, ibid., p. 275.
[8] Ibid., p. 219.
[9] Ibid., pp., 239-240.
[10] Ibid., p. 394.
[11] Ibid., p. 254.
[12] Record, Ohio Geol. Surv., Report 1888, vol. 6, p. 291.
[13] Ibid., p. 225.
[14] Ibid., pp. 246-247.
[15] Ibid., pp. 348-349.
[16] Ibid., p. 283.
[17] Ibid., p. 220.
[18] Ibid., p. 220.
[19] Ibid., pp. 223-224.
[20] Ibid., p. 203.
[21] Ibid., p. 428.
[22] Ibid., pp. 296-297.
[23] Ibid., pp. 213-214.
[24] Record, Ohio Geol. Surv., Report, 1888, vol. 6, pp. 361-363.
[25] Ibid., pp. 289-290.
[26] Ibid., pp. 321, 402-403.
[27] Ibid., pp. 372-375.

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OKLAHOMA.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Fort Reno	Canadian	1,200				
Oklahoma City		780				For oil or gas; unsuccessful.
Pawhuska	Osage	1,700				Oil well.
Mangum	Greer	500				For oil; unsuccessful.
Do	do	400				Abandoned.

OREGON.

Baker City	Baker	400		Many.		
Blalock	Gilliam	400				Unsuccessful.
Bliss Water Station		418	4-3¼	42	+10	Water tepid.
Burns	Harney	750	8			Abandoned. Only a very small flow at 300 feet.
Cleft Water Station		425	3	+28	+10	Water tepid.
Fort Stevens	Clatsop	400				Unsuccessful.
Do	do	800				Do.
Heppner	Morrow	650				
Portland	Multnomah	1,850				
The Dalles	Wasco	1,020	4¼-1¼			Bored for oil; no water below 350 feet.

PENNSYLVANIA.

Abbot Township	Potter	2,100				Oil boring; unsuccessful.
Do[1]	do	2,029				Small gas well.
Allegheny	Allegheny	1,760				Salt well.
Allegheny Township.[2]	Butler	1,055-1,408				Oil and gas wells.
Do.[3]	Venango	850				For oil; unproductive.
Do.[4]	Westmoreland.	1,250-2,847				For oil or gas; mostly unproductive.
Allen Township[5]	Washington	2,060				Gas well.
Altoona	Blair	2,006				Abandoned.
Amity Township	Erie	500-630				Several oil and gas wells.
Amwell Township[6]	Washington	2,385				For oil or gas; unproductive.
Ashland (vicinity)	Schuylkill	1,830	2	139	Flows.	Temp. 54°.
Ashland Township[7]	Clarion	1,128				For oil or gas; unproductive.

[1] Records, Pa. 2d Geol. Surv., Ann. Rept. for 1885, pp. 85-86.
[2] Ibid., Vol. II., pp. 238-240.
[3] Ibid., Vol. I[4], pp. 58-59.
[4] Ibid., Vol. I[5], pp. 211-215; Vol. II, pp. 277-278.
[5] Ibid., pp. 301-302.
[6] Ibid., pp. 307-308.
[7] Ibid., p. 230.

OHIO—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Napoleon [1]	Henry	1,889			+3	For gas; salt water at 1,889 feet.
Nelsonville [2]	Athens	570-950				Many salt wells; one small gas well.
Nevada [3]	Wyandot	2,000				Nothing but salt water.
Newark [4]	Licking	1,449-2,385				Several gas wells; small flows.
Newburg [5]	Cuyahoga	3,000	5¼			Some gas; much salt water.
New Carlisle [6]	Clark	1,060				For gas; unsuccessful.
New Lisbon [7]	Columbiana	1,350-1,370				Gas wells.
New London [8]	Huron	998-1,030				Three wells; nothing found except salt water.
New Vienna [9]	Clinton	1,785				Salt water at 1,785 feet.
Niles [10]	Trumbull	780-900				Two borings for gas; unsuccessful.
North Baltimore [11]	Wood	1,104½-1,295				Two gas and oil wells.
Do. [12]	do	1,190				
North Bend	Hamilton	1,350	5	200	+30	Good water.
Norwalk [13]	Huron	2,304				
Do	do	2,725	5¼			For oil or gas; unsuccessful.
Oak Harbor [14]		1,326-1,335				Three gas wells.
Oberlin	Ottawa	700				For oil or gas; unsuccessful.
Osborn	Greene	990				Unsuccessful.
Ottawa [15]	Putnam	1,314-1,365				Two oil and gas wells; small product; much salt water.
Oxford [16]	Butler	1,365				Shale gas and sulphur water only.
Painesville [17]	Lake	700-1,390				Several gas wells.
Patterson (2 miles south of). [18]	Hardin	1,330				Gas at 835 feet; large flow of water; unsuccessful.
Patterson (2 miles west of). [19]	do	1,300				Large flow of gas; also large flow of water.
Perrysburg [20]	Wood	+1,600				Several gas wells.
Piketon	Pike					
Pike Township [21]	Clarke	1,380				For gas; unsuccessful.
Piqua [22]	Miami	1,673				Do.
Plain City [23]	Madison	1,530-2,000	8		+13	Two wells; large flows of fine water from 350, 600, and 900 feet.
Plymouth [24]	Richmond	742				
Do. [25]	do	3,020				Salt and sulphur water at 850 feet.
Pomeroy	Meigs	1,550		20	−500	Salt well; some oil and gas.
Do	do	1,100				Several salt wells; flowed originally.
Do. [26]	do	767				
Pemberville	Wood					Unsuccessful.
Portage (vicinity) [27]	do	1,177				Do.

[1] Record, Ohio Geol. Surv., Report 1888, vol. 6, pp. 252-253.
[2] Ibid., p. 398.
[3] Ibid., p. 203.
[4] Ibid., pp. 317, 370-372.
[5] Record, Mich. Geol. Surv., 1881-1893, p. 73; Ohio Geol. Surv., Report, 1888, vol. 6, pp. 351-355; Ohio Geol. Surv., Report, vol. 1, pp. 352-355.
[6] Ohio Geol. Surv., Report, 1888, vol. 6, p. 280.
[7] Record, Ohio Geol. Surv., Report, vol. 6, 1888, p. 404.
[8] Ibid., pp. 440, 348-350.
[9] Ibid., pp. 296-297.
[10] Ibid., p. 401.
[11] Ibid., pp. 228-229; Pa. 2d Geol. Surv., Report for 1886, p. 786.
[12] Record, Ohio Geol. Surv., Report, 1888, vol. 6, p. 228.
[13] Ibid., pp. 440-441.
[14] Ibid., pp. 210-211.
[15] Ibid., p. 241.
[16] Ibid., p. 294.
[17] Ibid., pp. 427-428.
[18] Record, Ohio Geol. Surv., Report, 1888, vol. 6, pp. 221-222.
[19] Ibid., p. 222.
[20] Ibid., pp. 225, 788.
[21] Ibid., p. 280.
[22] Ibid., p. 273.
[23] Ibid., Report 1890, p. 246; U. S. Geol. Surv., 19th Annual Report, 1897-98, p. 663.
[24] Record, Ohio Geol. Surv., Report, 1888, vol. 6, p. 315.
[25] Ibid., pp. 302-303.
[26] Ibid., p. 397.
[27] Ohio Geol. Surv., Report 1888, vol. 6, pp. 164-165, 228.

OHIO—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Portage (vicinity)[1]	Wood	1,134				Unsuccessful.
Do.[1]	do					Large flow of gas.
Port Clinton[2]	Ottawa	+1,660				No product.
Portsmouth[3]	Scioto	2,000				No product, but salt water at 1,000 feet.
Prospect[4]	Marion	1,650				No product.
Quaker City[5]	Guernsey	1,347				Gas well.
Do	do	1,352				
Radcliff	Vinton	700 or 800				Water and gas.
Rarden	Scioto	1,710	10		—510	Water.
Rawson[6]	Hancock	1,337				For gas or oil; found salt water only.
Richland Furnace	Vinton					Gas well.
Ripley	Brown					No product.
Risingsun	Wood					Only small flow of oil.
Rockport[7]	Cuyahoga	527-1,335				Two gas wells; small flows.
Rutland Township	Meigs	1,560		10-25	—500	Salt water only.
Sabina	Clinton					
St. Henry[8]	Mercer	1,160-1,183				Gas well.
St. Marys[9]	Auglaize	1,230				Salt water only.
Do.[10]	do	1,132-1,225				Several oil wells.
Do.[10]	do	1,092-1,138				Several gas wells; large flows.
St. Paris[11]	Champaign	+1,000				Two unsuccessful borings.
Salem[12]	Columbiana	800-810+				Do.
Do	do	2,930				Unproductive.
Salem Township[13]	Wyandot	1,323				Small flow of oil.
Sandusky[14]	Erie	2,260				Some oil, gas, and salt water.
Saline Township[15]	Jefferson	1,105				Unproductive.
Sardis (SW of)[16]	Monroe	1,815				Oil well.
Sciotoville	Scioto	800				Unsuccessful.
Sevenmile	Butler	1,220	8		—6	Salt water and some gas.
Sheffield[17]	Lorain	720				Bored for oil; some gas found; unsuccessful.
Shelby[18]	Richland	1,480-1,796				Small flow of gas; 2 wells.
Sidney[19]	Shelby	1,205-1,250				Several gas wells; much salt water at 1,445 feet.
Somerset[20]	Perry	2,850			—400	Salt water at 2,850 feet.
South Kingsville[21]	Ashtabula	1,200				Gas well; some oil.
South Olive	Noble					Unproductive.
South Toledo[22]	Lucas	+1,012				Do.
Springfield[23]	Clarke	1,140-1,200				Several wells; unsuccessful.
Spring Valley[24]	Greene	1,500				Unsuccessful.
Steubenville[25]	Jefferson	1,290				Transient gas supply.
Do.[26]	do	2,519				
Stuartsville Township.[27]	Hancock	450				Oil wells.
Stryker	Williams	860				Mineral water at 230 feet.
Sunbury[28]	Delaware	2,530				
Tiffin[29]	Seneca	1,467-1,494				Several wells; large flow of gas; some oil.

[1] Ohio Geol. Surv., Report 1888, vol. 6, pp. 164-165, 228.
[2] Ibid., p. 212.
[3] Ibid., p. 395.
[4] Analysis, ibid., pp. 270-271.
[5] Record, ibid., pp. 324, 381-382.
[6] Ibid., p. 217.
[7] Record, Ohio Geol. Surv., Report 1888, vol. 6, pp. 432-434.
[8] Ibid., pp. 260-262.
[9] Ibid., pp. 255-258.
[10] Ibid., pp. 255-258.
[11] Ibid., pp. 276-277.
[12] Ibid., pp. 403-404, 452.
[13] Record, Pa. 2d Geol. Surv., Ann. Report for 1886, part 2, pp. 785-786.
[14] Record, Michigan Geol. Surv., 1881 1893, p. 83; Ohio Geol. Surv., Report, 1888, vol. 6, pp. 194-196.
[15] Record, Pa 2d Geol Surv., Report II, p. 282.
[16] Record, W. Va. Geol Surv., Reports, vol. 1, pp. 356-357
[17] Record, Ohio Geol. Surv., Report, 1888, vol. 6, p. 437.
[18] Ibid., pp. 316, 364-365.
[19] Ibid., pp. 264-266.
[20] Ibid., Report 1890, p. 247.
[21] Ibid., 1888, vol 6, pp. 423-424.
[22] Ibid., p. 225
[23] Ibid., pp. 278-280.
[24] Ibid., p. 291.
[25] Ibid., pp. 336-337.
[26] Record, Pa. 2d Geol. Surv., Ann. Report for 1886, part 2, p. 784.
[27] Ohio Geol. Surv., Report, 1890, pp. 219-220.
[28] Ibid., 1888, vol. 6, p. 283.
[29] Record, ibid., pp. 197-201.

OHIO—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Tiffin (vicinity of)[1]	Seneca	1,505-1,753				Several borings; all unsuccessful.
Tinney (south of)	Sandusky	1,220	8-5¼		—10	Gas, oil, and salt water.
Tippecanoe[2]	Miami	1,025				Small flow of gas.
Toledo[3]	Lucas	1,425				Several borings for gas and oil; unsuccessful.
Tontogany (2½ miles southeast).	Wood	1,425	8-5¼		—30	Some salt water, oil, and gas.
Toronto (4 miles west).[4]	Jefferson	1,455				For oil; unsuccessful.
Troy[5]	Miami	1,170				Some gas at 510, 680, and 880 feet.
Uniopolis	Auglaize					Very small flow of gas; abandoned.
Upper Sandusky[6]	Wyandot	1,340-1,347½				Two borings for oil or gas; unsuccessful.
Urbana[7]	Champaign	1,307-1,350				Very small showing of gas.
Vanlue[8]	Hancock	1,294				Small flow of gas.
Vanwert[9]	Vanwert	1,240				Very small flow of gas.
Vinton Township[10]	Vinton	490-1,057	10-5¼			Gas, oil, and salt water.
Wakeman	Huron	3,000				For oil; found salt water only at 1,950 feet.
Wapakoneta[11]	Auglaize	1,600				For oil or gas; salt water only.
Washington[12]	Fayette	1,850				For gas or oil: found salt water only
Waterville[13]	Lucas	1,153				Small flow of gas.
Wauseon[14]	Fulton	+2,158				Oil at 2,158 feet.
Wellington[15]	Lorain	1,030-1,050				Several small gas wells.
Westerville[16]	Franklin	+2,300				
Westminster[17]	Allen	1,400				For oil or gas; unsuccessful.
West Newton[18]	do	1,440				
Weston[19]	Wood	1,575				Oil, gas, and sulphur water.
Whartonsburg[20]		1,427				For oil or gas; unsuccessful.
Williamsburg	Clermont	660	6			Small flow of gas.
Do	do	660	6			Unsuccessful.
Willoughby[21]	Lake					Several small gas wells.
Wilmington[22]						
Woodville[23]	Sandusky	1,460				For oil or gas: only salt water found.
Wooster[24]	Wayne	1,805-2,000				Three borings for oil or gas; unsuccessful.
Xenia[25]	Greene	1,200				For oil or gas; unsuccessful.
Youngstown[26]	Mahoning	2,480				For gas or oil; unsuccessful.
Zanesville[27]	Muskingum	1,098-2,019				Three wells; some oil.

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[15] Ibid., pp. 348-349.
[16] Ibid., p. 283.
[17] Ibid., p. 220.
[18] Ibid., p. 220.
[19] Ibid., pp. 223-224.
[20] Ibid., p. 203.
[21] Ibid., p. 428.
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OKLAHOMA.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Fort Reno	Canadian	1,200				
Oklahoma City		780				For oil or gas; unsuccessful.
Pawhuska	Osage	1,700				Oil well.
Mangum	Greer	500				For oil; unsuccessful.
Do	do	400				Abandoned.

OREGON.

Baker City	Baker	400		Many.		
Blalock	Gilliam	400				Unsuccessful.
Bliss Water Station		418	4-3¼	42	+10	Water tepid.
Burns	Harney	750	8			Abandoned. Only a very small flow at 300 feet.
Cleft Water Station		425	3	+28	+10	Water tepid.
Fort Stevens	Clatsop	400				Unsuccessful.
Do	do	800				Do.
Heppner	Morrow	650				
Portland	Multnomah	1,850				
The Dalles	Wasco	1,020	4¼-1¼			Bored for oil; no water below 350 feet.

PENNSYLVANIA.

Abbot Township	Potter	2,100				Oil boring; unsuccessful.
Do[1]	do	2,029				Small gas well.
Allegheny	Allegheny	1,760				Salt well.
Allegheny Township.[2]	Butler	1,055-1,408				Oil and gas wells.
Do.[3]	Venango	850				For oil; unproductive.
Do.[4]	Westmoreland.	1,250-2,847				For oil or gas; mostly unproductive.
Allen Township[5]	Washington	2,060				Gas well.
Altoona	Blair	2,006				Abandoned.
Amity Township	Erie	500-630				Several oil and gas wells.
Amwell Township[6]	Washington	2,385				For oil or gas; unproductive.
Ashland (vicinity)	Schuylkill	1,830	2	130	Flows.	Temp. 54°.
Ashland Township[7]	Clarion	1,128				For oil or gas; unproductive.

[1] Records, Pa. 2d Geol. Surv., Ann. Rept. for 1885, pp. 85-86.
[2] Ibid., Vol. II., pp. 238-240.
[3] Ibid., Vol. I[4], pp. 58-59.
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[5] Ibid., pp. 301-302.
[6] Ibid., pp. 307-308.
[7] Ibid., p. 230.

PENNSYLVANIA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Baden (1 mile north)[1]	Beaver	1,366				For oil or gas.
Barnet Township[2]	Forest	2,428				For oil or gas; unsuccessful.
Beaver Falls[3]	Beaver	2,330				Do.
Beaver Falls (2 miles above).[4]	do	982				Gas well.
Beaver Township[5]	Clarion	1,001-1,200				For oil or gas.
Belle Vernon[6]	Fayette	2,005				Small gas well.
Benezette[7]	Elk	721	3			For oil or gas; abandoned.
Black Ash[8]	Crawford	777				Do.
Blacklick (vicinity)[9]	Indiana	1,728				Do.
Black's Siding[10]	Venango	1,650				For oil or gas; unproductive.
Blacksville[11]	Greene	500?				For oil.
Blairsville[12]	Westmoreland.	2,060				For oil or gas; abandoned.
Bloomfield Township.[13]	Crawford	590-1,000				Several oil wells.
Bradford[14]	McKean	1,065				For oil.
Bradford (vicinity)[15]	do	1,010-1,719				Numerous oil and gas wells.
Brady Township[16]	Butler	1,458-1,596				For oil.
Bradys Bend	Armstrong	+1,089				Oil and gas well.
Bradys Bend Township.[17]	do	1,100-1,260				For oil.
Bridgeville (vicinity).[18]	Allegheny	2,250				
Bridgewater (near)	Beaver					For gas; small supply.
Brookston	Forest	2,200				For oil or gas; unsuccessful.
Brookville[19]	Jefferson	3,100				For oil or gas; unproductive.
Do.[20]	do	1,700				Gas well.
Brookville Borough[21]	do	2,430				Do.
Brownsville[22]	Fayette	+2,106				Do.
Brush Run[23]	Clarion	1,047-1,636				Oil and gas wells.
Brushton Station	Allegheny	1,615				Unsuccessful.
Bryn Mawr	Montgomery	550	8	83	−310	
Do	do	600	6	120		
Burrell Township[24]	Westmoreland.	2,500				
Do.[25]	do	1,850				For oil or gas; abandoned.
Butler[26]	Butler	3,055				Do.
Do	do	1,500-1,950				Several oil and gas wells.
Butler (3 miles south)	do	3,008	5			
Do.[27]	do	1,500 1,795				Gas and oil wells.
Butler Township[28]	do	1,524-1,637				For oil.
Cambria Mill[29]	Cambria	653(?)				Gas well.
Cameron Station (½ mile northeast).[30]	Cameron	971				For oil.
Cannonsburg (vicinity).[31]	Washington	1,763-2,502				Numerous oil and gas wells; some unproductive.
Canton Township[32]	do	2,727				For oil or gas.
Carlisle (1½ miles SE)	Cumberland	864	5-4½			
Carlisle (5 miles west).	do	420	5-4½			

[1] Record, Pa. 2d Geol. Surv., Reports, Vol. I[5], p. 232.
[2] Ibid., p. 154.
[3] Ibid., Vol. III, pp. 401-404.
[4] Ibid., Vol. I[4], pp. 142 143.
[5] Ibid., Vol. II, pp. 228 229.
[6] Ibid., Ann. Rept., 1886, part 2, pp. 778-779.
[7] Ibid., Vol. I[4], pp. 133 134; Vol. R R, p. 248.
[8] Ibid., Vol. I[5], p. 186.
[9] Ibid., p. 168.
[10] Ibid., pp. 184-185.
[11] Ibid., Vol. K, pp. 108-109.
[12] Ibid., Vol. I[5], pp. 224-225.
[13] Records, Pa. 2d Geol. Surv., Reports, Vol. Q, pp. 224-226; Vol. II, pp. 273-274; Vol. I[4], p. 119.
[14] Ibid., Vol. I[4], pp. 97-103.
[15] Ibid., Vol. I[4], p. 89; Vol. R, pp. 287-290.
[16] Ibid., Vol. G[4], pp. 150-151; Vol. III, pp. 418-419.
[17] Ibid., Vol. II, pp. 258-259.
[18] Ibid., Vol. I[5], p. 272.
[19] Ibid., pp. 163-164.
[20] Ibid., Vol. I[4], p. 139.
[21] Ibid., Ann. Rept., 1886, part 2, p. 778.
[22] Ibid., Vol. I[5], pp. 317-318.
[23] Ibid., pp. 235-236.
[24] Ibid., pp. 212-213.
[25] Ibid., Ann. Rept. for 1886, part 2, pp. 686-687.
[26] Ibid., Vol. I[5], pp 193-194.
[27] Ibid., pp 209-210
[28] Ibid., Ann Rept. for 1886, part 2, pp. 711-713.
[29] Ibid., Vol. HH, pp. 176-180.
[30] Ibid., Vol. RR, part 2, p. 23; vol. G[4], p. 138.
[31] Ibid., Vol. I[5], pp. 281-297.
[32] Ibid., pp. 279-280.

PENNSYLVANIA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Carmichaels (vicinity).[1]	Greene	2,432				For oil or gas.
Carpenters Station (near).[2]	Westmoreland.	1,541				Do.
Chambersburg	Franklin	+400				
Chambersburg (2 miles west).	do	600	6		−17	Water at 427 feet.
Cherry Grove Township.[3]	Warren	1,548-2,004				Several oil and gas wells; some unproductive.
Cherry Tree Borough.[4]	Cambria	653				Gas well.
Church Run[5]	Crawford	415-700				Several oil wells.
Clarion[6]	Clarion	1,238-1,367				Several oil wells; one unproductive.
Clearfield (2 miles southwest).[7]	Clearfield	2,900				For oil or gas; unproductive.
Clearfield Township).[8]	Butler	1,558-1,925				Several oil and gas wells; one unsuccessful.
Clinton Township[9]	Venango	836-1,266				Several oil wells; mainly productive.
Cooksburg[10]	Forest	2,100-2,726				For oil or gas, unsuccessful.
Cooksburg (vicinity).[11]	Clarion	843-2,050				For oil or gas, one unproductive.
Collier Township[12]	Allegheny	2,400				Gas well.
Concord Township[13]	Crawford	845				Oil and gas well.
Conneautville (1 mile below).[14]	do	750				For oil or gas.
Cornplanter Township.[15]	Venango	451-924				Do.
Corry[16]	Erie	2,340				Gas and oil well.
Corydon (1 mile from).[17]	McKean	1,532-1,601				Gas wells.
Corydon Township	Warren	720				For oil.
Coudersport[18]	Potter	2,100				Small gas well.
Cranberry Township.[19]	Venango	600-1,506				Numerous oil and gas wells, mainly productive.
Crawford Township	Clinton	458				Coal prospect, unsuccessful.
Crescent Township[20]	Allegheny	2,106				For oil or gas, unproductive.
Cresson[21]	Cambria	677				For oil.
Criswell (vicinity)[22]	Armstrong	1,394-1,618				Oil and gas wells.
Darlington[23]	Beaver	2,444				For oil or gas, unproductive.
Degolia (near)[24]	McKean	1,404				For oil or gas.
Delano	Schuylkill	515	2			Coal prospect.
Demmler	Allegheny	1,600				For oil or gas, abandoned.
Dennis Run[25]	Warren	426-632				Several oil and gas wells.
Dicksonburg	Crawford	680?				Oil well.
Dixmont[26]	Allegheny	1,802				Oil and gas well.
Donegal Township[27]	Butler	1,565-1,740				Many oil and gas wells.
Doylestown	Bucks	750				
Dubois Station[28]	Clearfield	3,020				For oil or gas, unproductive.
Dunkard Township	Greene					Several oil wells.

[1] Record, Pa. 2d Geol. Surv., Reports, Vol. I[5], pp. 315-316.
[2] Ibid., Ann. Rept. for 1886, part 2, pp. 725-726.
[3] Ibid., Vol. I[4], pp. 26-27, 375-376.
[4] Ibid., p. 146.
[5] Ibid., Vol. II, pp. 66-69.
[6] Ibid., Vol. I[5], pp. 157-159; Vol. III, pp. 413-414.
[7] Ibid., Vol. I[5], pp. 166-167.
[8] Ibid., Ann. Rept. for 1886, part 2, p. 178; Vol. II, pp. 266-268.
[9] Ibid., Vol. II, pp. 219-222.
[10] Records, Pa. 2d Geol. Surv., Reports, Vol. I[5], pp. 159-161.
[11] Ibid., Vol. I[4], pp. 140-141.
[12] Ibid., Vol. I[5], pp. 261-262.
[13] Ibid., Vol. Q[4], p. 212.
[14] Ibid., Vol. Q[4], pp. 216, 234-236.
[15] Ibid., Vol. I[4], pp. 59-61.
[16] Ibid., Vol. I[4], p. 228.
[17] Ibid., Vol. I[4], pp. 259-261.
[18] Ibid., Ann. Rept., 1886, part 2, pp. 775-776.
[19] Ibid., Vol. II, pp. 203-207, 210-214; Vol. I[4], pp. 62-63.
[20] Record, Pa. 2d Geol. Surv., Reports, Vol. I[5], pp. 264-265.
[21] Ibid., Vol. HH, p. 30.
[22] Ibid., Vol. II, pp. 253-258.
[23] Ibid., Ann. Rept., 1886, part 2, pp. 780-781.
[24] Ibid., Vol. I[4], p. 90.
[25] Record, Am. Phil. Soc., Proc., vol. 16, pp. 367-370.
[26] Record, Pa. 2d Geol. Surv., Reports, Vol. I[5], pp. 257-258.
[27] Ibid., pp. 199-203; Vol. II, pp. 263-265.
[28] Ibid., Vol. I[5], pp. 165-166.

PENNSYLVANIA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Eagle Station	Delaware	1,700		Few.		
East Bethlehem Township.[1]	Washington	604				Salt well, abandoned.
East Brookside	Schuylkill	585	8			Oil well.
East Deer Township[2]	Allegheny	1,194–1,243				Several gas wells, one abandoned.
Easton	Northampton.	500		105	−43	
East Pike Run Township.[3]	Washington	1,950				Gas well.
Ebensburg	Cambria	1,000	5¼	Many.	No flow.	
Edenburg[4]	Clarion	1,268				Good oil well.
Edenburg (1 mile southeast).[5]		1,046				
Eldred Township[6]	Warren	415–481				Oil and gas wells.
Elkland	Tioga					For oil or gas.
Elklick	Somerset	+1,500				
Do	do	2,900				For oil.
Elk Township[7]	Clarion	977–1,450				Several oil or gas wells, some unproductive.
Do.[8]	Warren	1,500				For oil, abandoned.
Elrod	Allegheny	±1,500				For oil or gas, abandoned.
Do.[9]	do	1,486			Flows	For oil or gas, unsuccessful.
Elrod (1 mile north)	do	1,510				For gas, abandoned.
Elrod Township[10]	Warren	588–914				For oil or gas.
Emelton (vicinity)[11]	Venango	720–1,000				Numerous oil wells, mainly productive.
Emporium[12]	Cameron	1,410				For oil.
Do	do	+400				
Emporium (4 miles northwest).[13]	do	1,607				For oil or gas, unproductive.
Enterprise[14]	Warren	474–487				Several oil wells.
Enterprise (vicinity).[15]	do	462–800				Do.
Erie[16]	Erie	4,460				For oil or gas, abandoned.
Do.[17]	do	1,250–1,418				Gas wells.
Do	do	470–800				Numerous gas and oil wells.
Fairoaks[18]	Beaver	1,645				Small oil well.
Fairoaks (vicinity)[19]	do	1,606				Gas well.
Falls Creek Station (near).[20]	Jefferson	3,040				Do.
Fairview Township[21]	Butler	1,421–1,694				Numerous oil and gas wells.
Do.[22]	Erie	700–1,000				Several gas wells.
Farrentown[23]	Armstrong	1,140–1,166				Several oil and gas wells.
Fawn Township		1,147–1,550				Several good gas wells.
Forest City	Wayne					Coal prospect.
Foresthill	Union	480			Flows.	Sulphur water.
Fort Hunter	Dauphin	2,675	6			Abandoned.
Forward Township[24]	Butler	1,553–1,683				Oil and gas wells.
Foxburg[25]	Armstrong	805–944				Small oil wells.
Franklin (¼ mile northeast).[26]	Venango	490			Flows.	Good oil well.
Franklin (8 miles south).[27]	do	3,880				For oil or gas, unproductive.
Franklin Township[28]	Washington	2,608				For oil or gas, abandoned.

[1] Record, Pa. 2d Geol. Surv., Reports, Vol. K, pp. 178–179.
[2] Ibid., Vol. I[5], pp. 237–238.
[3] Ibid., pp. 302–303.
[4] Ibid., Vol. I[4], pp. 139–140.
[5] Ibid., Vol. II, p. 229.
[6] Ibid., Vol. I[4], pp. 52–53.
[7] Ibid., Vol. II, pp. 230–232; Vol. III, pp, 415–416.
[8] Ibid., Vol. I[4], p. 30.
[9] Record, Pa. 2d Geol. Surv., Report for 1886, part 2, pp. 667–668.
[10] Ibid., Vol. II, pp. 195–196.
[11] Ibid., pp. 222–225.
[12] Ibid., Vol. G[4], p. 140.
[13] Ibid., p. 141.
[14] Ibid., Vol. II, pp. 65–66.
[15] Record, Am. Phil. Soc., Proc., vol. 16, pp. 367–369.
[16] Record, Pa. 2d Geol. Surv., Reports, Vol. I[3], pp. 187–192.
[17] Ibid., Vol. I[4], pp. 122, 290.
[18] Ibid., Vol. I[5], pp. 232–233.
[19] Ibid., p. 233.
[20] Ibid., p. 164.
[21] Records, Pa. 2d Geol. Surv., Reports, Vol. II. pp. 246–262.
[22] Ibid., Vol. Q[4], pp. 262–263.
[23] Ibid., Vol. II, pp. 242–243.
[24] Ibid., Vol. I[5], p. 208.
[25] Ibid., Vol. II, pp. 237–238.
[26] Ibid., Vol. I[4], p. 65.
[27] Ibid., Vol. I[5], pp. 185–186.
[28] Ibid., p. 279.

PENNSYLVANIA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Franklin Township[1]	Allegheny	1,905-2,150				Several oil or gas wells.
Do.[2]	do	1,492-±1,500				For oil or gas.
Gaines[3]	Tioga	1,345				For oil or gas, abandoned.
Gallagher Township	Clinton	3,525				
Georgetown[4]	Beaver	1,430				For oil or gas, abandoned.
German Township[5]	Fayette	1,196				Gas well.
Gerties Run[6]	Allegheny	±1,600				For oil or gas, abandoned.
Gibsonia (¼ mile west).[7]	do	2,017				For oil or gas.
Girard Township[8]	Erie	980				For oil, unsuccessful.
Good Intent (2¼ miles southwest).[9]	Washington	2,720				For oil or gas, unproductive.
Great Belt City (vicinity).[10]	Butler	1,875				
Greece City (3 miles west).[11]	do	1,500				Do.
Greece City (vicinity).[12]	do	1,423-1,530				Several oil and gas wells.
Greene Township	Greene					Oil and gas well.
Greenfield	Erie	780				Large gas well.
Greensboro[13]	Greene	668				Oil well.
Greensburg (4 miles southwest).[14]	do	769				Do
Hamilton Township[15]	McKean	2,011				Oil well.
Hamlin Township[16]	do	2,315-2,400				Several oil wells; some unproductive.
Do.[17]	do	1,613-1,768				Several oil wells; one abandoned.
Hammersley Fork	Clinton	−1,800				For oil.
Hanover Township[18]	Beaver	1,644				
Harrisburg	Dauphin	2,800	6			For gas. Abandoned.
Do	do	+400				Two wells.
Harrison Township[19]	Allegheny	1,109-1,200				Several gas wells.
Do.[20]	Potter	1,995				
Harrisville (vicinity.)[21]	Butler	880-1,367				For gas or oil.
Hazleton	Luzerne	482-690	2			Coal prospects.
Hebron[22]	Potter	1,286				For oil.
Hempfield Township.[23]	Westmoreland.	1,255				Gas well.
Herman[24]	Butler	1,784-1,901				Several oil and gas wells.
Hickory	Washington					Gas well.
Hickory (2¼ miles southwest).[25]	do	2,245				Large gas well.
Hickory (2 miles southeast).[26]	do	2,205				Large flow of gas.
Hickory (vicinity)[27]	do	700-1,151				Several large gas wells.
Highland Township[28]	Elk	2,095-2,448				Many oil and gas wells; some abandoned.
Hollenback	Bradford	600				
Homestead (vicinity).[29]	Allegheny	1,744				For oil or gas.
Homewood Station	Beaver	1,500(?)				Do.

[1] Records, Pa. 2d Geol. Surv., Reports, Vol. I[4], pp. 251-254.
[2] Ibid., Vol. I[4], p. 144.
[3] Ibid., Vol. I[5], pp. 147-148.
[4] Ibid., p. 233.
[5] Ibid., pp. 321-322.
[6] Ibid., Ann. Rept. for 1886, part 2, pp. 742-744.
[7] Ibid., Vol. I[5], p. 242.
[8] Ibid., Vol. Q[4], p. 259.
[9] Ibid., Vol. I[5], pp. 305-306.
[10] Ibid., Vol. I[4], p. 138.
[11] Ibid., p. 141.
[12] Ibid., Vol. II, pp. 247-248.
[13] Ibid., Ann. Rept. for 1886, part 2, p. 774.
[14] Ibid., Vol. I[4], p. 145.
[15] Record Pa. 2d Geol. Surv., Reports, Vol. R, pp. 266-267.
[16] Ibid., Vol. I[6], pp. 151-152.
[17] Ibid., Vol. R, pp. 179-182; Vol. I[4], pp. 111-113.
[18] Ibid., Vol. I[5], pp. 235-236.
[19] Ibid., Ann. Rept. for 1886, part 2, pp. 684-686.
[20] Ibid., Vol. G[3], pp. 80-81.
[21] Ibid., Ann. Rept. for 1886, part 2, pp. 718-719.
[22] Ibid., Vol. G[3], p. 79.
[23] Ibid., Vol. I[5], p. 223.
[24] Ibid., pp. 195-197.
[25] Ibid., Ann Rept. for 1886, part 2, pp. 754-755.
[26] Ibid., pp. 769-772.
[27] Ibid., pp. 758-760; Am. Phil. Soc., Proc., vol. 16, p. 489.
[28] Ibid., Pa. 2d Geol. Surv., Ann. Rept. for 1886, part 2, pp. 707-709; Vol. I[6], p. 155.
[29] Ibid., pp. 744-746.

PENNSYLVANIA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Homewood Station (vicinity).[1]	Beaver	925				For oil or gas.
Honesdale (5 miles from).	Wayne	2,500				Two oil wells; abandoned.
Honesdale (6 miles north).[2]	do	1,505				For oil.
Hopewell Township[3]	Beaver	1,490-1,572				
Horatio	Jefferson	543			−10	
Howe Township[4]	Forest	1,475-1,985				Several oil wells.
Do.(?)[5]	do	2,233				Gas well.
Hulton Station (near)	Allegheny					For gas; unsuccessful.
Humes Station (near).[6]	Clinton	1,821				For oil or gas; unproductive.
Huntingdon	Huntingdon	400				Several wells.
Hyner Station (near)[7]	do	1,187				For oil.
Independence Township.[8]	Beaver	+1,223				For oil or gas; unproductive.
Irwin	Westmoreland.	4,380				
Do.[9]	do	2,340				Do.
Jacks Run[10]	Allegheny	1,724		Many.	Flows.	Fresh water at 1,600 feet.
Jackson Township[11]	Venango	688				Oil well.
Jamestown[12]	Mercer	1,063				Oil and gas well.
Jefferson[13]	Greene	2,658				
Jefferson Center[14]	Butler	1,732				Oil well.
Jefferson Township[15]	Allegheny	2,014				Gas well.
Jenks Township[16]	Forest	400-1,003				Several gas or oil wells; unproductive.
Do.[17]	do	1,310-2,505				Several wells; mainly unproductive.
Jermyn	Lackawanna.	780	6	25		
Johnsonburg Station.[18]	Elk	2,510				Large gas well.
Johnstown[19]	Cambria	2,856				For oil or gas; unproductive.
Johnstown (4 miles west).[20]	do	2,500				Do.
Jones Township[21]	Elk	1,335-1,756				Two oil wells; one abandoned.
Karns City (¼ mile south).[22]	Butler	1,454				
Kingsley Township[23]	Forest	2,200				For oil or gas; unproductive.
Kinzua Township[24]	Warren	1,048-2,285				Several oil wells; mainly unproductive.
Knox Township[25]	Jefferson	1,608-2,000				Moderate gas wells.
Lafayette Township.[26]	McKean	2,111-2,490				Several oil and gas wells.
Lardens Mills[27]	Butler	1,140				Gas well.
Latrobe[28]	Westmoreland.	1,980				For oil or gas.
Lawrenceburg (south of).[29]	Armstrong	1,017				
Layton Station[30]	Fayette	2,100				For oil or gas; unproductive.
Leboeuf	Erie	780				Oil and gas well.
Limestone (3 miles south).	McKean	1,130				Oil well.

[1] Record, Pa. 2d Geol. Surv., Reports, Vol. QQ, pp. 250-251.
[2] Ibid., Vol. G^6, pp. 91-93.
[3] Ibid., Vol. I^5, pp. 234-235.
[4] Ibid., Vol. I^4, pp. 79-81; Ann. Rept for 1886, part 2, p. 700.
[5] Ibid., Ann. Rept. for 1886, part 2, pp. 700-701.
[6] Ibid., Vol. I^5, p. 197.
[7] Ibid., Vol. G^4, pp. 131-134.
[8] Ibid., Ann. Rept. for 1886, part 2, pp. 779-780.
[9] Ibid., Vol. I^5, pp. 221-222.
[10] Ibid., Ann. Rept. for 1886, part 2, pp. 748-749.
[11] Ibid., Vol. II, p. 201.
[12] Ibid., pp. 274-275.
[13] Ibid., Vol. I^5, pp. 314-315.
[14] Ibid., Ann. Rept. for 1886, part 2, pp. 716-717.
[15] Ibid., pp. 752-753.
[16] Ibid., Reports, Vol. I^4, pp. 81-83.
[17] Ibid., pp. 83-86; Ann. Rept. for 1886, part 2, pp. 702-705.
[18] Ibid., Ann. Rept. for 1886, part 2, pp. 710-711.
[19] Ibid., Reports, Vol. I^5, pp. 169-170.
[20] Ibid., pp. 170-171.
[21] Ibid., Vol. I^4, pp. 127-128.
[22] Ibid., Vol. II, pp. 262-263.
[23] Ibid., Ann. Rept. for 1886, part 2, pp. 703-704.
[24] Ibid., Vol. I^4, pp. 27-29.
[25] Ibid., Vol. I^6, pp. 162-163.
[26] Records, Pa. 2d Geol. Surv., Repts., Vol. I^5, pp. 152-53.
[27] Ibid., Vol. II., pp. 270-271.
[28] Ibid., Vol. I^5, pp. 223-224.
[29] Ibid., Vol. II., p. 243.
[30] Ibid., Vol. I^5, pp. 318-319.

PENNSYLVANIA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Littlestown	Adams	500				
Little Washington	Washington					Two gas wells.
Lockhaven	Clinton	3,525	6¼			For oil or gas; unsuccessful.
Lottsville [1]	Warren	960-1,515				Two oil or gas wells; abandoned.
Lovelton (near)	Wyoming					Deep well.
Mahanoy City (near)	Schuylkill	1,130	2	Many.	Flows.	Temp. 51°.
Manchester [2]	York	1,520				For oil or gas.
Marienville (near) [3]	Forest	1,305				
Marion Township [4]	Butler	765				
Mars Station (near) [5]	do	1,900				For oil or gas; unproductive.
Marshall Township [6]	Allegheny	1,830				
Masontown [7]	Fayette	2,525				Gas well.
McCandless Township. [8]	Allegheny	2,110				For oil or gas.
McDonald [9]	Washington	2,342				Gas well.
McKeesport Borough	Allegheny	1,640				Do.
Meadville [10]	Crawford	900				Several oil wells in this vicinity.
Mercer (near) [11]	Mercer	1,702				Gas well.
Miam Hollow [12]	McKean	1,390				
Middlesex (near) [13]	Mercer	2,030				For oil or gas; unproductive.
Middlesex, West (1 mile south). [14]	do	3,484				Do. Do.
Middlesex Township. [15]	Butler	1,785-1,930				Several oil and gas wells.
Mill Creek Township. [16]	Clarion	2,323				For oil or gas; unproductive.
Millvale [17]	Allegheny	1,655				For oil or gas; unsuccessful.
Millville [18]	Clarion	2,280				Oil and gas well.
Monongahela [19]	Washington	2,152-2,218				Gas wells.
Moon Township [20]	Allegheny	1,800-2,337				Several oil and gas wells.
Do. [21]	Beaver	1,257-1,680				Several oil or gas wells.
Monroeville (1 mile southeast). [22]	Allegheny	1,798		Many.	Flows.	Fresh water.
Montana	Columbia	717-722	2			
Mount Carmel	Northumberland.	900	2			
Mount Morris (near). [23]	Greene	1,772				Oil well.
Murrysville [24]	Westmoreland.	1,337-1,440				Numerous oil and gas wells.
Murrysville (vicinity). [25]	do	1,312-1,465				Large oil field.
Neilltown (vicinity) [26]	Forest	780-995				Numerous oil and gas wells; some unproductive.
Neville Island [27]	Allegheny	1,686-1,837				Several oil and gas wells.
Newcastle [28]	Lawrence	2,700	5¼			For oil or gas; unproductive.
Newcastle (vicinity)	do	1,912				Gas and oil well.
Do	do	700-900				Several wells.
New Sewickley Township. [29]	Beaver	1,820				For oil or gas; unproductive.
Newton Hamilton	Mifflin	800				Not in operation.
Nineveh (vicinity) [30]	Greene	2,970-3,221				Several wells.

[1] Records, Pa. 2d Geol. Surv., Repts., Vol. I[5], pp. 232-233.
[2] Ibid., Vol. II, pp. 278-279.
[3] Ibid., Vol. G[4], pp. 146-147.
[4] Ibid., Ann. Rept. for 1886, part 2, p. 720.
[5] Ibid., Vol. I[5], p. 210.
[6] Ibid., pp. 242-243.
[7] Ibid., pp. 322-323.
[8] Ibid., p. 254.
[9] Record, W. Va. Geol. Surv., Repts., Vol. 1, 1889, pp. 214-30.
[10] Pa. 2d Geol. Surv., Repts., Vol. Q[4], p. 175.
[11] Record, ibid., Vol. II., p. 275.
[12] Record, Pa. 2d Geol. Surv., Reports, Vol. I[4], p. 97.
[13] Ibid., Vol. I[5], pp. 229-230.
[14] Ibid., pp. 230-231.
[15] Ibid., Vol. II, p. 271; Vol. I[5], pp. 197-198; Vol. III, pp. 404-405.
[16] Ibid., Vol. II, pp. 232-234.
[17] Ibid., Ann. Rept. for 1886, part 2, pp. 741-742.
[18] Ibid., Reports, Vol. III, pp. 411-412.
[19] Ibid., Vol. I[5], p. 301.
[20] Ibid., pp. 263-268.
[21] Ibid., Ann. Rept. for 1886, part 2, pp. 688-689.
[22] Ibid., pp. 746-747.
[23] Record, Pa. 2d Geol. Surv., Reports, Vol. I[5], pp. 316-317.
[24] Ibid., pp. 215-218.
[25] Ibid., Ann. Rept. for 1886, part 2, pp. 673-674, 721-724.
[26] Ibid., Reports, Vol. I[4], pp. 69-77.
[27] Ibid., Vol. I[5], pp. 258-260.
[28] Ibid., Vol. G[4], pp. 151-152; Vol. II, pp. 275-276.
[29] Ibid., Vol. I[5], pp. 231-232.
[30] Ibid., pp. 308-312.

PENNSYLVANIA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
North Mahoning Township.	Indiana	2,615(?)				Gas well.
North Strabane Township.	Washington	1,800				Small gas well.
North Warren (near)[1]	Warren	475-965				Numerous gas and oil wells; some unproductive.
Do.[2]	do	1,200-1,400				Several oil and gas wells; unproductive.
Do.[3]	do	1,835				For oil; abandoned.
Oakdale Station (3 miles north).[4]	Allegheny	2,164				For oil or gas.
Oakland Township[5]	Venango	640				
O'Harra Township[6]	Allegheny	1,950-2,060				For oil or gas; unproductive.
Ohio Township[7]	do	1,715-2,240				Numerous gas and oil wells.
Oil City[8]	Venango	1,070				
Do.[9]	do	540-818				Several oil wells.
Oil Creek Township	Crawford	3,500				For oil.
Do.[10]	Venango	902-1,000				Several oil wells.
Olmstead (near)	McKean	1,040				Oil well.
Oneida Station (1½ miles east).[11]	Butler	2,135				Gas well.
Osterburg (2 miles northwest).	Bedford	800			+3	
Parker City[12]	Armstrong	850				Oil well.
Parker Township[13]	Butler	1,183-1,418				For oil.
Pennsburg	Montgomery	1,000				
Penn Township[14]	Allegheny	1,750				For oil or gas; unproductive.
Do.[15]	Butler	1,528-1,825				Numerous oil and gas wells; some good producers.
Do.[16]	Westmoreland.	2,495				Large gas well.
Do.[17]	do	1,580-1,690				Several large gas wells.
Perry Township[18]	Armstrong	801-950				For gas or oil.
Do.[19]	do	791				Oil and gas well.
Petroleum Center[20]	Venango	500-900				Numerous oil wells; mainly productive.
Petrolia (vicinity)[21]	Butler	1,400-1,631				Numerous gas and oil wells.
Philadelphia (Melrose).	Philadelphia	553	10-8	150	−6	
Philadelphia (Ambler Works).	do	500	6	250		
Philadelphia (Morocco Works).	do	500	6	500		
Philadelphia (N. & G. N. Taylor).	do	670	12	250		
Philadelphia (League Island).	do	600				
Philadelphia (Hog Island).	do	456				
Philadelphia (Twenty-fourth and Brown streets).	do	495	6	60		
Philadelphia (Thirteenth and Mount Vernon streets).	do	3,061	8	2,600		
Philadelphia (Seventh and Callow Hill streets).	do	452	8	150		

[1] Record, Pa. 2d Geol. Surv., Reports, Vol. I[4], pp. 10-15.
[2] Ibid., pp. 11-13.
[3] Ibid., p. 12.
[4] Ibid., Vol. I[5], pp. 262-263.
[5] Ibid., Vol. II, p. 202.
[6] Ibid., Vol. I[5], pp. 239-241.
[7] Ibid., pp. 244-251.
[8] Ibid., Vol. III, p. 416.
[9] Record, Am. Philos. Soc., Proc., Vol. 16, pp. 482-487; Pa. 2d Geol. Surv., Reports, Vol. II, pp. 204-205.
[10] Ibid., Pa. 2d Geol. Surv., Reports, Vol. I[4], pp. 53-54.
[11] Ibid., Pa. 2d Geol. Surv., Ann. Rept., 1886, part 2, pp. 717-718.
[12] Ibid., Reports, Vol. II, p. 242.
[13] Ibid., pp. 243-246.
[14] Ibid., Ann. Rept. for 1886, part 2, pp. 749-750.
[15] Ibid., pp. 713-716; Vol. I[5], pp. 203-206.
[16] Ibid., pp. 219-220.
[17] Ibid., pp. 218-219; Ann. Rept. for 1886, part 2, pp. 724-725.
[18] Ibid., Vol. II, pp. 240-241.
[19] Ibid., Vol. III, pp. 416-417.
[20] Records, Am. Phil. Soc., Proc., vol. 16, pp. 470-477.
[21] Records, Pa. 2d Geol. Surv., Reports, Vol. II, pp. 260-261, 283-296.

PENNSYLVANIA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Philadelphia (Crown and Willow streets).	Philadelphia.	1,000	10	100	.....	
Philadelphia (Fifteenth and Market streets).	....do.....	500	8	100	.....	
Philadelphia (108 South Broad street).	....do.....	484	8	60	.....	
Philadelphia (Broad street below Locust).	....do.....	525	8	110	.....	
Philadelphia (Amholt & Schaefer Brewing Co.).	....do.....	1,500	.....	50	.....	
Pike Township [1]	Potter	1,835	.....	.....	.....	For oil or gas; unproductive.
Do.[2]	....do.....	1,500	.....	.....	.....	For oil or gas; abandoned.
Pinegrove	Schuylkill	450	8	Many.	No flow.	
Pinegrove Township.[3]	Venango	1,869-2,060	.....	.....	.....	Several oil wells.
Do.[4]	....do.....	912-1,070	.....	.....	.....	For oil.
Do.[5]	Warren	750-1,830	.....	.....	.....	Several oil and gas wells; small production.
Pine Township [6]	Allegheny	2,010	.....	.....	.....	Two gas and oil wells.
Do.[7]	Armstrong	1,410-1,693	.....	.....	.....	Oil and gas wells.
Pioneer (vicinity) [8]	Venango	437-980	.....	.....	.....	Numerous oil wells; large production.
Pithole City [9]	....do.....	747	.....	.....	.....	For oil or gas; unproductive.
Pittsburg	Allegheny	5,500	.....	.....	.....	No water below 1,100.
Pittsburg (Lang avenue and Grazier street).[10]	....do.....	4,700?	.....	.....	.....	For oil or gas; abandoned.
Pittsburg (Twenty-first Ward).	....do.....	1,616	.....	.....	.....	Gas well.
Do	....do.....	1,620	.....	.....	.....	For oil or gas; abandoned.
Pittsburg (Twenty-fifth Ward).[11]	....do.....	3,000	5¼-5½	.....	.....	Large gas well.
Pittsburg (Twenty-fourth Ward).[12]	....do.....	1,826	.....	.....	.....	Gas well.
Pittsburg (Fourteenth Ward).[13]	....do.....	2,007	5¼	.....	.....	Dry hole.
Pittsburg (near steel works).[14]	....do.....	2,360	.....	.....	.....	For oil or gas.
Pittsburg (just outside of city).	....do.....	1,901	.....	.....	.....	Gas well.
Do	....do.....	1,600	.....	.....	.....	Small flow of gas.
Pittsburg (Thirty-fourth Ward).[15]	....do.....	2,014	5¼	.....	.....	For gas; unsuccessful, owing to salt water.
Pittsburg (Twenty-first Ward).[16]	....do.....	1,635	.....	.....	.....	
Pittsburg (Twenty-third Ward).	....do.....	1,600	.....	.....	.....	For gas; flooded with salt water.
Pittsburg (Thirty-third Ward).[17]	....do.....	1,577	.....	.....	.....	For oil or gas; abandoned on account of salt water.
Pittsburg (Fifteenth Ward).[18]	....do.....	1,576	.....	.....	.....	For oil or gas; abandoned.
Pittsburg (Twenty-first Ward).	....do.....	1,575	.....	.....	.....	For gas; flooded with water.
Pittsburg (Twenty-sixth Ward)	....do.....	1,535	.....	.....	.....	For oil or gas; abandoned on account of salt water.

[1] Records, Pa. 2d Geol. Surv., Reports, Vol. I[5], pp. 148-149.
[2] Ibid., pp. 149-150.
[3] Ibid., p. 184.
[4] Ibid., Vol. I[4], p. 64.
[5] Ibid., pp. 16-18.
[6] Ibid., Vol. I[5], pp. 243-244.
[7] Ibid., Vol. III, pp. 409-410; Vol. II, p. 277.
[8] Ibid., Vol. II, pp. 43-64; Am. Phils. Soc., Proc., vol. 16, pp. 468-471.
[9] Records, Pa. 2d Geol. Surv., Reports, Vol. I[5], p. 179.
[10] Ibid., pp. 276-277.
[11] Ibid., Ann. Rept., 1886, part 2, pp. 730-732.
[12] Ibid., pp. 733-736.
[13] Ibid., pp. 736-737.
[14] Record, Pa. 2d Geol. Surv., Reports, Vol. III, pp. 398-400.
[15] Ibid., Ann. Rept. for 1886, part 2, pp. 739-741.
[16] Ibid., Vol. I[5], pp. 275-276.
[17] Ibid., Ann. Rept. for 1886, part 2, p. 738.
[18] Ibid., p. 741.

PENNSYLVANIA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Smethport (west of).[1]	McKean	2,004				For oil; abandoned.
Smethport (vicinity).[2]	do	1,293-1,900				Several oil and gas wells; small production.
Smiths Ferry[3]	Beaver	500				For oil or gas; unproductive.
Snowden Township[4]	Allegheny	2,348				Gas well.
Snydersburg[5]	Clarion	1,307				Oil well.
Sodom (near)[6]	Allegheny	2,275-2,502				Several gas wells.
South Fayette Township.[7]	do	2,140				Oil well.
South Shenango Township.[8]	Crawford	1,065				Do.
South Strabane Township.[9]	Washington	2,410-2,503				Gas wells.
South Versailles Township.	Allegheny	1,550				Gas well.
Do[10]	do	1,510-1,624				For oil or gas; abandoned on account of salt water.
Southwest Township.[11]	Warren	500-1,550				Numerous oil and gas wells.
Sparta Township[12]	Crawford	465-1,507				Several oil and gas wells; some productive.
Spartansburg (2¼ miles southeast).[13]	do	745				Gas well.
Spence Run[14]	Allegheny	1,990				For oil or gas.
Spring Township	Crawford	512				Gas well.
Spring Creek Township.[15]	Elk	880				For oil; unsuccessful.
Do.[16]	Warren	600-1,061				Several oil and gas wells; small production.
Springdale Station (near).	Allegheny					For gas; unsuccessful.
Springfield Township.	Erie	400				For oil; unsuccessful.
Stoneboro (near)[17]	Mercer	950				Oil well.
Stoneham (vicinity)[18]	Warren	1,025-1,600				Several oil and gas wells; mostly productive.
Sugar Run[19]	McKean	970				Oil well.
Sugar Creek Township.[20]	Venango	583-606				Two oil wells; one abandoned.
Sulphur Run[21]	do	925-1,350				Two oil wells.
Summit[22]	Butler	1,822				Gas well.
Summit Township[23]	do	1,735				Oil well.
Do	Erie	400				Gas well.
Tarentum	Allegheny	+1,160				For gas or oil; abandoned.
Tarentum (vicinity).[24]	do	482-1,705				Several gas and oil wells; small production.
Tarentum (3¼ miles northeast).[25]	do	2,010				For oil or gas; unproductive.
Tarentum (1¼ miles southeast).	Westmoreland.					For oil or gas; abandoned.
Taylorstown[26]	Washington	2,350-2,760				Several gas and oil wells.
Throop	Lackawanna.	2,380				Water in small quantity.

[1] Record, Pa. 2d Geol. Surv., Reports, Vol. R, pp. 271-272.
[2] Ibid., pp. 272-276.
[3] Ibid., Vol. II, pp. 281-282.
[4] Ibid., Vol. I[5], pp. 273-274.
[5] Ibid., Vol. G[4], p. 149; Vol. I[4], p. 140.
[6] Ibid., Vol. I[5], pp. 269-273.
[7] Ibid., p. 273.
[8] Ibid., Vol. Q[4], p. 153.
[9] Ibid., Vol. I[5], p. 280.
[10] Ibid., Ann. Rept. for 1886, Part II, pp. 751-752.
[11] Record, Pa. 2d Geol. Surv., Reports, Vol. I[4], pp. 49-52; Vol. I[5], p. 855; Am. Phil. Soc., Trans., vol. 16, pp. 346-367.
[12] Ibid., Vol. I[5], pp. 186-187; Vol. Q[4], p. 227.
[13] Ibid., Vol. II, p. 69; Am. Philos. Soc., Proc., vol. 16, p. 493.
[14] Ibid., Pa. 2d Geol. Surv., Ann. Rept., 1886, part 2, p. 744.
[15] Ibid., Vol. I[4], pp. 132-133.
[16] Ibid., pp. 252-253.
[17] Ibid., p. 121.
[18] Ibid., pp. 20-23.
[19] Ibid., Vol. I[4], p. 91.
[20] Ibid., Vol. II, pp. 200-201.
[21] Ibid., Vol. I[5], pp. 182-183.
[22] Ibid., Vol. I[3], p. 404.
[23] Ibid., Vol. II, pp. 268-269.
[24] Ibid., Vol. I[3], pp. 405-408.
[25] Ibid., Vol. I[5], pp. 238-239.
[26] Ibid., pp. 298-299.

PENNSYLVANIA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Tidioute (vicinity)[1]	Warren	403-715				Numerous oil and gas wells; none large producers, and many abandoned.
Tionesta (near)[2]	Forest	437				Oil and gas well.
Tionesta Township[3]	do	554-2,177				For oil or gas; unproductive.
Titusville	Crawford	600	10			
Titusville (near)[4]	do	3,553				For oil or gas.
Titusville (vicinity)[5]	do	400-806				Numerous oil and gas wells.
Do.[6]	Venango	538-966				Do.
Toby Township[7]	Clarion	1,400	8			Oil well.
Towet City	Schuylkill	418				
Tremont	do		8			Do.
Triumph[8]	Warren	+472				For oil; unsuccessful.
Triumph (vicinity)[9]	do	739-815				Several oil wells.
Triumph Township[10]	do	2,464-2,700				For oil or gas; unsuccessful.
Do.[11]	do	805-908				Numerous oil and gas wells.
Troy Township	Crawford	500-1,700				Several oil and gas wells; some unproductive.
Tryonville (vicinity)	do	600-1,000				Oil and gas wells.
Tuna Valley[12]	McKean	1,035-1,919				Several oil and gas wells.
Turkey City (near)[13]	Clarion	1,150				For oil or gas.
Union City[14]	Erie	1,523				For oil or gas; unsuccessful.
Union Township	do	1,600				For oil; unsuccessful.
Uniontown (3 miles northwest).[15]	Fayette	2,001				Gas well.
Upper Middletown[16]	do	2,440				For oil or gas; unproductive.
Upper St. Clair Township.[17]	Allegheny	2,442				Gas well.
Venice (1 mile northwest).[18]	Washington	2,247	7¼-5¼			For oil or gas; unsuccessful.
Wall Station (near)	Allegheny	1,850		Many.	Flows.	Water charged with soda; temp. 65°-70°; also gas well.
Waltz Mill (near)[19]	Westmoreland.	1,769-3,151				Two borings for oil or gas; unproductive.
Warren (near)[20]	Warren	581-1,065				Numerous oil and gas wells; some good producers.
Washington[21]	Washington	2,285-2,599				Several oil and gas wells.
Washington (near)[22]	do	1,977-2,420				Do.
Washington Township.[23]	Westmoreland.	1,301-1,638				Gas wells.
Waterford (2 miles west).	Erie	650				Oil and gas wells.
Watson Township[24]	Warren	1,936				For oil or gas; unproductive.
Wayne Township[25]	Lawrence	790				For oil; unsuccessful.
Do	Erie	600				Gas and oil well.
Do.[26]	Crawford	600-1,100				Several oil and gas wells.
Waynesburg[27]	Greene	2,745				Oil well; abandoned.

[1] Record, Pa. 2d Geol. Surv., Reports, Vol. I[4], pp. 31-48; Am. Phil. Soc., Proc., vol. 16, pp. 372-374.
[2] Record, Am. Philos. Soc., Proc., vol. 16, p. 488.
[3] Ibid., Pa. 2d Geol. Surv., Reports, Vol. I[4], pp. 77-79; Ann. Rept. for 1886, part 2, pp. 705-707.
[4] Ibid., Vol. Q[4], p. 184; Vol. I[3], p. 154; Vol. I[4], p. 284.
[5] Ibid., Am. Philos. Soc., Proc., vol. 16, pp. 490-493; Pa. 2d Geol. Surv., Reports, Vol. I[4], pp. 118-119.
[6] Ibid., Pa. 2d Geol. Surv., Reports, Vol. I[4], p. 56.
[7] Ibid., Vol. I[3], pp. 412-413.
[8] Record, Am. Philos. Soc., Proc., vol. 16, p. 494.
[9] Ibid., pp. 370-372.
[10] Records, Pa. 2d. Geol. Surv., Reports, Vol. I[4], pp. 280-283.
[11] Ibid., Vol. I[3], pp. 173-174; Vol. I[3], pp. 283-286.
[12] Ibid., Vol. I[4], pp. 87-92.
[13] Ibid., Vol. II, p. 227.
[14] Ibid., Vol. I[4], p. 121.
[15] Ibid., Vol. I[5], pp. 320-321.
[16] Ibid., p. 319.
[17] Ibid., pp. 271-272.
[18] Record, Pa. 2d Geol. Surv., Ann. Rept. for 1886, part 2, pp. 759-760.
[19] Ibid., Vol. I[5], pp. 225-227.
[20] Ibid., Vol I[4], pp. 1-9.
[21] Ibid., Ann. Rept. for 1886, part 2, pp. 764-767.
[22] Ibid., pp. 760-769.
[23] Ibid., pp. 726-730.
[24] Ibid., Vol. I[4], p. 20.
[25] Ibid., Vol. QQ, p. 89.
[26] Ibid., Vol. Q[4], pp. 122-125.
[27] Ibid., Ann. Rept. for 1886, part 2, pp. 772-773.

PENNSYLVANIA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Waynesburg (vicinity).[1]	Greene	2,675–2,900				Two oil and gas wells; one unproductive.
Wellersburg	Somerset	1,207				Good water.
Wellsboro	Tioga					
West Alexander (3 miles west).[2]	Washington	3,200				For oil or gas; unproductive.
West Amity Station (near).[3]	do	+2,390				Gas well.
West Branch Township.[4]	Potter	1,750–2,750				For oil; unsuccessful.
West Deer Township.[5]	Allegheny	2,243				For oil or gas; unproductive.
West Middletown[6]	Washington	3,455				For oil or gas; abandoned.
Wicks Station[7]	Butler	912				
Wilcox (4½ miles north).[8]	Elk	1,850				Small oil well.
Wilkesbarre	Luzerne	536	2			
Do	do	466				For water; unsuccessful.
Willow Tree[9]	Greene	2,165				For oil or gas; abandoned.
Winfield Township[10]	Butler	1,685				For oil or gas; unsuccessful.
Woodcock Township	Crawford	+600				For oil; unsuccessful.
Woodrow (near)[11]	Washington	+4,303				Gas well.
Wrightsville (1 mile northeast).[12]	Warren	1,200				Abandoned as dry hole.

[1] Record, Pa. 2d Geol., Surv., Reports, Vol. I[5], p. 312.
[2] Ibid., pp. 304–315.
[3] Ibid., p. 307.
[4] Ibid., Ann. Rept. for 1885, pp. 86–91.
[5] Ibid., Vol. I[5], p. 241.
[6] Ibid., Ann. Rept. for 1886, part 2, pp. 756–758.
[7] Ibid., p. 720.
[8] Ibid., Vol. G[4], pp. 143–146.
[9] Ibid., Vol. I[5], p. 316.
[10] Ibid., Ann. Rept. for 1886, part 2, p. 716.
[11] Ibid., pp. 755–756.
[12] Ibid., Vol. I[4], p. 236.

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Pennsylvania Second Geological Survey, Report of Progress, 1876–1877, Oil Well Records and Levels, by J. F. Carll, Vol. II, 398 pages, Harrisburg, 1877.

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Pennsylvania Second Geological Survey, Annual Report, 1886, part 2, Report on the Oil and Gas Regions, by J. F. Carll, pp. 575–918, Harrisburg, 1887.

Pennsylvania Second Geological Survey, Seventh Report on the Oil and Gas Fields of Western Pennsylvania for 1887–1888, by J. F. Carll, Vol. I[3], 356 pages, Harrisburg, 1890.

RHODE ISLAND.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Providence	Providence	400	6	85	No flow.	
Do	do	460	6	110	No flow.	
Saylesville	do	1,438		15	No flow.	Abandoned.

SOUTH CAROLINA.

Abbeville	Abbeville	504	8	80	−3	
Aiken[1]	Aiken	558	8–6	50	−170	In granite.
Bamberg[2]	Barnwell	470–555	1¼–2	35–40	+12–30	Several wells.
Beaufort[3]	Beaufort	800				
Camden	Kershaw	618–625		Many.	−20	Two wells.
Charleston[4]	Charleston	1,970		250	+4	Temp. 99.5°.
Do.[5]	do	1,260		30	+25	Saline water; temp. 87°.
Do	do	1,950	3¼	167		Temp. 99°.
Do	do	1,970	2 1/16	104		Do.
Do	do	2,050	4	451		Do.
Do	do	1,945	5	695		Do.
Charleston (vicinity)[6]	do	425–475				Several wells.
Chester	Chester	700				In granite; unsuccessful.
Do	do	500	8			Unsuccessful.
Florence[7]	Florence	1,335	10–8	100	−20	Lowest water at 1,215 to 1,220.
Do	do	420		Many.		Fine water.
Georgetown	Georgetown	400?		Not any		
Green Pond	Colleton	503	3	1	Flows.	Temp. 70°.
Greenwood	Abbeville	400	8	40	−4	
Hampton	Hampton	800			Flows.	
Do	do	583	6	Many.	−9	Soft, irony water.
Jacksonboro	Colleton	420	3	4	Flows.	Temp. 72°.
Johns Island		500	6	11	Flows.	Temp. 70°.
Marion	Marion	1,244	8–6	½	Flows.	
Mays River Neck		800			−1	Very sulphurous water.
Orangeburg[8]	Orangeburg	1,160	6–2¼	Many.	−52	Pumped at 300 feet.
Peeples	Hampton	850	6	100	Flows.	Temp. 76°.
Sullivans Island	Laurens	1,308	12–3	10		Temp. 87°.
Varnville	Hampton	983	6	Many.	−12	
Walterboro	Colleton	490	6	Many.	−30	Soft water.

[1] Record, U. S. Geol. Surv., Bull. No. 138, p. 220.
[2] Ibid., p. 221.
[3] Analysis, Ibid., p. 217.
[4] Record, Municipal Report of City of Charleston, 1881, Artesian Wells, Report of Scientific Committee, pp. 3–4, plate.
[5] Analysis, U. S. Geol. Surv., Bull. No. 138, p. 212.
[6] Ibid., pp. 214–216.
[7] Record and Analysis, Ibid., pp. 218–219.
[8] Record, Ibid., p. 220.

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SOUTH DAKOTA.

[Arranged by counties.]

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Plankinton Township.	Aurora	775	4¼	200	+127	
Plankinton	do	830	4¼-3	225	+209	Flows at 540 and 740 feet also.
Do	do	745	4	60		
White Lake	do	863	4	150	+80	Flows at 790 and 850 feet.
Crystal Lake Township, sec. 17.	do	850	4¼	600	+127	
T. 105, R. 63, sec. —	do	475	2	5		
T. 105, R. 66, sec. 24	do	953	2	115		
T. 104, R. 63, sec. 22[1]	do	525	4-3	168		
T. 104, R. 66, sec. 2	do	844	2	150		A flow also at 710 feet.
T. 104, R. 63, sec. 21	do	528	4¼	150	+103	
Do	do	525	4¼	150		
T. 104, R. 63, sec. 1	do	470	2	4		
T. 104, R. 66, sec. 3	do	922	2	75		
T. 103, R. 63, sec. 26[1]	do	490	4	10		
Do	do	530	2	10		
T. 103, R. 63, sec. 35	do	484	4-3			
T. 103, R. 63, sec. 32	do	623	3-2	15		A flow also at 520 feet.
T. 103, R. 66, sec. 34	do	842	6			Flows at 650 and 842 feet.
T. 103, R. 63, sec. —	do	705	3	200		
T. 103, R. 63, sec. 28	do	716				Flows at 600 and 675 feet.
T. 103, R. 63, sec. —	do	530	2	30		
T. 103, R. 63, sec. 13	do	420	2	30		
T. 102, R. 66, sec. 17	do	835	4	400		
T. 102, R. 63, sec. 10[1]	do	613	2	3		
Hitchcock[2]	Beadle	953	4-3	1,260	+345	
Huron[2]	do	906	6	1,500	+276	Flows at 712 and 772 feet also.
Do	do	847	6-4	600	+276	Flows at 776 and 826 feet.
Do	do	1,040	8	350		A flow at 756 feet also.
Huron (1 mile sw.)	do	1,080	5¼	1,500		A flow at 900 feet also.
Huron[2]	do	960	10-5¼	2,250	+380	Temp. 70°. Several flows 240 to 960 feet.
Wolsey[2]	do	930	8-5	330		Flows at 490, 808, 858, and 893 feet also.
T. 113, R. 64, sec. 15	do	1,066	4	600	Flows.	
T. 113, R. 64, sec. 29	do	1,118	4	1,435	+403	
T. 112, R. 61, sec. 30[3]	do	917	6-4		Flows.	Flows at 770 and 800 feet also.
T. 111, R. 61, sec. 19	do	836	3	360	+338	
T. 111, R. 61, sec. 31	do	792	3	200	+292	
T. 110, R. 62, sec. 11	do	1,080	5¼	1,500	Flows.	Flow at 900 feet also.
T. 110, R. 60, sec. 29	do	930	4	930	+230	
T. 109, R. 62, sec. 30	do	813	3	250	+288	
Scotland	Bonhomme	590	6			
Do[4]	do	587		9		
Springfield[4]	do	592	8	3,292	+198	
Do	do		4			
Tyndall[4]	do	736	4¼	1,000	+69	
Do	do	752	8			
Choteau Creek	do	862?		1,400	+143	
Do	do	897	6	1,600	+133	
T. 96, R. 59, sec. 15[5]	do	700	2			
Do.[5]	do	590	7	1	+126	
Do.[5]	do	645	3		+149	
T. 94, R. 61, sec. 22[4]	do	1,074¼	3-2¼	¼	+6	
T. 94, R. 60, sec. 9	do	768	2	60		
T. 94, R. 58, sec. 32	do	640	2	75		
T. 93, R. 59, sec. 1	do	646	1	30	+143	
T. 93, R. 58, sec. 5[6]	do	660	3	95	+104	
T. 95, R. 59, sec. 34	do	730	2	97	+82	
T. 60, R. 93, sec. 5[7]	do	825				
T. 94, R. 58, sec. 19	do	576	3	11		
Aberdeen[8]	Brown	955	8-3	Many.	+230	Flows at 925 and 940 feet.

[1] Record, U. S. Geol. Surv., 18th Ann. Rpt., part 4, Pl. XL.
[2] U. S. Geol. Surv., 17th Ann. Rept., part 2, pp. 22-23.
[3] Ibid., Pl. 76.
[4] Record, U. S. Geol. Surv., 17th Ann. Rept., part 2, p. 58.
[5] At Hutterisches Colony, Record, U. S. Geol. Surv., 18th Ann. Rept., part 4, p. 587.
[6] Record, U. S. Geol. Surv., 17th Ann. Rept., part 2, p. 50.
[7] Record, U. S. Geol. Surv., 18th Ann. Rept., part 4, p. 586.
[8] Record, U. S. Geol. Surv., 17th Ann. Rept., part 2, pl. 72.

SOUTH DAKOTA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Aberdeen [1]	Brown	1,050	6-5	1,060	+317	
Do. [1]	do	918	3 3/16	330	+92	Flows at 879 and 905 feet.
Do. [1]	do	1,004	6-4	825	+143	
Do. [1]	do	1,066	8-2	Many.	Flows.	Flows at 910, 921, and 1,020 feet also.
Do. [1]	do	1,300	8-4¼	1,080	+196	Flows at 920, 995, and 1,077 feet.
Aberdeen, T. 123, R. 63, sec. 17.	do	1,117	4¼	Many.	Flows.	Flows at 925 and 1,090 feet.
Aberdeen, T. 123, R. 63, sec. 18.	do	1,015	4¼	300	+288	Flows also at 928 feet.
Columbia [1]	do	964	4¼	940	+368	Five flows 721-927 feet.
Frederick [1]	do	1,139	6-4	139	+161	Flows at 985 and 1,045 feet also.
Groton [1]	do	960	5 3/16-3¼			
Do	do	922	6-3	830	+310	
T. 127, R. 63, sec. 12 [2]	do	856			Flows.	
T. 127, R. 63, sec. 21 [2]	do	800			Flows.	
T. 126, R. 60, sec. 32	do	1,030	6		+80	
T. 126, R. 61, sec. 31 [2]	do	965			Flows.	
T. 125, R. 61, sec. 3 [2]	do	716			Flows.	
T. 124, R. 60, sec. 31 [2]	do	942	4-2	150	+315	
T. 123, R. 60, sec. 8 [2]	do	977		105	+184	
Chamberlain [3]	Brule	600	8		+219	
Do. [3]	do	685	10-8	4,350	+253	
Do	do	1,026	6	3,000	Flows.	
Do	do	815		300	Flows.	Flows at 716, 750, and 780 feet also.
Do	do	563	2		Flows.	
Do	do	600	2	2	Flows.	
Kimball [3]	do	1,068	4¼	185	+46	
T. 105, R. 68, sec. 26 [3]	do	935	6	815	+173	Flows at 750, 825, and 875 feet also.
T. 105, R. 68, sec. 3	do	987	6		Flows.	
T. 104, R. 70, sec. 33	do	900	6		Flows.	
T. 103, R. 71, sec. 12	do	1,030	6	700	Flows.	
T. 103, R. 68, sec. 1	do	1,065	6	750	+46	
T. 103, R. 68, sec. 27	do	980	8		Flows.	
T. 102, R. 70, sec. 21	do	1,185	6	800	Flows.	
T. 102, R. 67, sec. 18	do	1,050	6	1,000	Flows.	
T. 102, R. 68, sec. 16	do		6		Flows.	
T. 102, R. 70, sec. 9	do	1,165		Many.	Flows.	
T. 102, R. 70, sec. 15	do	1,100	6	800	Flows.	
T. 102, R. 70, sec. 2	do	1,027		Many.	Flows.	
T. 102, R. 71, sec. 2	do	1,227	8	600	Flows.	
T. 102, R. 71, sec. 2	do	1,230	8	900	Flows.	
T. 101, R. 68, sec. 12	do	937	6	1,098	Flows.	Flows at 753, 786, and 851 feet also.
T. 101, R. 68, sec. 21	do	962	8-4	Many.	Flows.	
Crow Creek Agency [4]	Buffalo	780	6		+414	Temp. 72°; flows at 409 feet also.
Belle Fourche	Butte	525	8	60	+70	Two wells; another flows at 410 feet.
Chandler	Charles Mix	900	2			Uncompleted.
Greenwood [5]	do	651	6	3,000	+274	Temp. 70°; several flows 420-641 feet.
Lake Andes [5]	do	755¼	8-6	1,500	+161	Temp. 70°; flows at 623 and 725 feet also.
Do. [5]	do	802	8-6	1,500	+161	Temp. 70°.
T. 100, R. 69, sec. 9	do	980	3	125	Flows.	Chalk at 210 feet.
T. 100, R. 71, sec. 29	do	785	8	500	Flows.	
T. 100, R. 71, sec. 18	do	868	8	2,352	Flows.	
T. 100, R. 68, sec. 13	do	720	2-1	Several.	Flows.	
T. 100, R. 68, sec. 9	do	830	2-1¼	7	Flows.	
T. 99, R. 69, sec. 19	do	966	2-1¼	60	+115	Flows at 779, 803, 838, and 860 feet also.
T. 100, R. 71, sec. 26	do	688	8	1,700	Flows.	Flows at 500 and 614 feet also.
T. 99, R. 67, sec. 18	do	769	2-1	7	Flows.	Water at 515 feet.
T. 99, R. 67, sec. 21 [6]	do	907	8-4¼	40	Flows.	
T. 98, R. 68, sec. 13	do	1,006	6-4		No flow.	
T. 98, R. 64, sec. 20	do	772	2	200	+120	

[1] Record, U. S. Geol. Surv., 17th Ann. Rept., part 2, pp. 16-18, pl. 72.
[2] Record, U. S. Geol. Surv., 17th Ann. Rept., part 2, pp. 15-17.
[3] Ibid., pp. 42-48.
[4] Record, U. S. Geol. Surv., 18th Ann. Rept., part 4, p. 573.
[5] Record, U. S. Geol. Surv., 18th Ann. Rept., part 4, p. 570.
[6] Record, U. S. Geol. Surv., 17th Ann. Rept., part 2, pp. 44-45.

SOUTH DAKOTA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Clark	Clark	1,200				Two wells; unsuccessful.
T. 117, R. 59, sec. 22 [1]	do	1,200	6			
T. 95, R. 52, sec. 9	Clay	500	3-2	3	Flows.	
T. 94, R. 52, sec. 11	do	402	2	5	Flows.	
T. 94, R. 52, sec. 15	do	400	1¼	Many.	Flows.	
T. 94, R. 53, sec. 33	do	500	2	Few.	Flows.	
T. 93, R. 51, sec. 29	do	400	1¼	3	Flows.	
T. 93, R. 51, sec. 31	do	410	1	1	Flows.	
T. 92, R. 51, sec. 33	do	400	3-2	Few.	Flows.	
Vermilion	do	507	3	Few.	Flows.	
Buffalo Gap	Custer	800				Two borings; no water.
Mitchell [2]	Davison	548			+16	
Do	do	586	8	600	+64	Flows at 285, 445, and 560 feet.
Mitchell (12 miles southwest). [2]	do	433	2	20	Flows.	
Mitchell (6 miles northeast). [2]	do	472	2	40	Flows.	
Mitchell	do	550	2	60	+30	
Mount Vernon	do	442	2	8	Flows.	
Mount Vernon (14 miles southeast).	do	515	4¼-3¼	50	Flows.	
T. 104, R. 60, sec. 17 [2]	do	400		100	Flows.	
T. 104, R. 62, sec. 9 [2]	do	550	2-1	130	Flows.	
T. 104, R. 60, sec. 17 [2]	do	456	3	10	Flows.	
T. 103, R. 62, sec. 4	do	495	4	30	Flows.	
T. 103, R. 62, sec. 3 [2]	do	646	4¼	700	Flows.	
T. 104, R. 61, sec. —	do	415		30	Flows.	
T. 104, R. 61, sec. 12	do	410	2	40	Flows.	
T. 104, R. 62, sec. 18	do	408	2	20	Flows.	
T. 104, R. 62, sec. 21	do	424	3	156?	Flows.	
T. 104, R. 62, sec. 12	do	416	2	5	Flows.	
T. 104, R. 62, sec. 3	do	601	4-3	130	Flows.	
T. 104, R. 62, sec. 7	do	444	2	15	Flows.	
T. 104, R. 62, sec. 35	do	479	5-4	Many.	Flows.	
T. 104, R. 60, sec. 35	do	507	4¼-3	40	Flows.	
T. 104, R. 62, sec. 6	do	458	1	3	Flows.	
T. 104, R. 61, sec. 29	do	419	2	50	Flows.	
T. 104, R. 61, sec. 8	do	577	2	50	Flows.	
T. 104, R. 61, sec. 18	do	653	2-1	90	Flows.	
T. 104, R. 61, sec. 33	do	425	3	210	Flows.	
T. 104, R. 61, sec. 20	do	420	2	22	Flows.	
T. 103, R. 61, sec. 19	do	411	2	120	Flows.	
T. 103, R. 62, sec. 2	do	420	2	60	Flows.	
T. 103, R. 62, sec. 14	do	450	2	60	Flows.	
T. 103, R. 62, sec. 10	do	495	3	35	Flows.	
T. 103, R. 62, sec. 11	do	408	2	45	Flows.	
T. 103, R. 62, sec. 15	do	406	2	60	Flows.	
T. 103, R. 61, sec. 19	do	410	2	110	Flows.	
T. 102, R. 62, sec. 9	do	460	2	90	Flows.	
T. 102, R. 62, sec. 31	do	642	2-1¼	20	Flows.	
T. 102, R. 62, sec. 29	do	485	2-1¼	30	Flows.	
T. 102, R. 62, sec. 6	do	460	2	25	Flows.	
T. 101, R. 61, sec. 25	do	520	2	27	Flows.	
T. 101, R. 61, sec. 28	do	530	2	15	Flows.	
T. 101, R. 61, sec. 21	do	535	1¼	35	Flows.	
T. 101, R. 61, sec. 2	do	425	2	30	Flows.	
T. 101, R. 60, sec. 32	do	435	2	25	Flows.	
T. 101, R. 60, sec. 9	do	477	2		Flows.	
T. 101, R. 60, sec. 29	do	413	2	35	Flows.	
S. S. Slade's well	do	440	2	10	Flows.	
Andover [4]	Day	1,075	6-4¼	300	+207	
Webster	do	1,400				Small flow only at 1,100 feet.
Cheyenne Agency [5]	Dewey	1,337	4	500	+472	Temperature 80°.
Armour	Douglas	800	8	1,500	Flows.	
Do. [6]	do	737	6	1,500	+126	
Delmont [6]	do	821	2	60	Flows.	
Flensburg [6]	do	611	2	60	Flows.	
Do	do	651	2		Flows.	
Do	do	775	2	65-70	Flows.	
T. 100, R. 64, sec. 26 [6]	do	937	6	900	+72	

[1] Record, U. S. Geol. Surv., 18th Ann. Rept., 1897, part 4, pp. 18, 21.
[2] Record, U. S. Geol. Surv., 17th Ann. Rept., part 2, pp. 39-40, 44.
[3] Record, U. S. Geol. Surv., 18th Ann. Rept., part 4, p. 575.
[4] Record, U. S. Geol. Surv., 17th Ann. Rept., part 2, p. 19.
[5] Record, U. S. Geol. Surv., 18th Ann. Rept., part 4, p. 588.
[6] Record, U. S. Geol. Surv., 17th Ann. Rept., part 2, pp. 46-50.

SOUTH DAKOTA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
T. 100, R. 64, sec. 26	Douglas	975	4	1,000	Flows.	
T. 100, R. 62, sec. 18	do	1,025		1,025	Flows.	
T. 100, R. 63, sec. 15	do	750	4	600-700	Flows.	
T. 100, R. 62, sec. 16	do	600	2	Many.	Flows.	
T. 98, R. 65, sec. 2 [1]	do	860	6	900	Flows.	
T. 99, R. 63, sec. 35	do	703¼	8-6	2,100	+172	
T. 99, R. 65, sec. 14	do	925	4	600-700	Flows.	
T. 99, R. 65, sec. —	do	1,010	6	1,000	Flows.	
T. 98, R. 65, sec. 2	do	901	8-6	650	Flows.	
Ipswich	Edmunds	1,265	4¼-3¼	Many.	+244	
Ardmore	Fall River	1,500				Unsuccessful.
Argentine [2]	do	550			Flows.	
Edgemont [3]	do	1,125		Several.	— 60	Plugged at 700 feet; water from 509 feet.
Edgemont (near)	do	960		Several.	— 30	Water from 578 feet.
Minnekahta [4]	do	1,348		None.		
Faulkton	Faulk	1,032		100	Flows.	
Orient (4 miles N E.) [5]	do	1,215	6-5¼	950	Flows.	
T. 113, R. 69, sec. —	Hand	1,200			Flows.	Flows at 1,087 and 1,127 feet also.
T. 113, R. 67, sec. 25	do	1,137	6-3	480	Flows.	
T. 112, R. 68, sec. 7	do	1,200	4	50	Flows.	
St. Lawrence	do	1,272		Few.	+ 92	First flow at 1,070 feet.
Miller [6]	do	1,139	6¼-4¼	360	+276	
T. 112, R. 68, sec. 10	do	1,140	3¼		Flows.	
T. 112, R. 67, sec. 33	do	1,375	3	1,000	+273	
T. 112, R. 67, sec. 18	do	1,343	3	350	+287	
T. 104, R. 57, sec. 8 [7]	Hanson	589	2-1¼	50	Flows.	
T. 104, R. 58, sec. 14 [7]	do	528	2-1¼	30	Flows.	
T. 104, R. 58, sec. 13 [7]	do	550	2	150	Flows.	
T. 104, R. 57, sec. 22	do	543	2	50	Flows.	
T. 104, R. 58, sec. 9	do	535	2	5	Flows.	
T. 104, R. 58, sec. 17	do	440	1	Few.	Flows.	
T. 104, R. 57, sec. 8	do	600	1¼	20	Flows.	
T. 104, R. 58, sec. 12 [8]	do	483	4	35	+46	
T. 104, R. 57, sec. 27	do	508	2	4	Flows.	
T. 104, R. 57, sec. 7	do	510	3-2	16	Flows.	
East Pierre [9]	Hughes	1,192		900	+380	
Harrold [9]	do	1,453	4	84	+62	Temp. 95°.
Pierre	do	1,160		600	Flows.	Temp. 92°.
Menno	Hutchinson	417	6			Small flow.
Northwest corner of county. [10]	do	560		10		
Parkson [10]	do	542	3	30	+46	
Parkson (1 mile southwest). [10]	do	515		50	Flows.	
Tripp (4 miles north) [10]	do	580-540	2	9	Flow.	Three wells.
Tripp	do	815	6	700	+21	
T. 97, R. 57, sec. 21	do	747	2	6	Flows.	
T. 98, R. 61, sec. —	do	482		60	Flows.	
T. 98, R. 60, sec. 21	do	559	2	50	Flows.	
T. 99, R. 60, sec. 7	do	527	2	150	Flows.	
T. 100, R. 61	do	419-585	3-1¼	90-1	Flow.	Fourteen wells.
T. 100, R. 60	do	420-462	2	10-3	Flow.	Three wells.
T. 100, R. 61, sec. 25 [11]	do	458	2		Flows.	
T. 99, R. 61	do	490-572	2-1¼	50-8	Flow.	Fourteen wells.
T. 99, R. 60 [11]	do	485	2	25	Flows.	
T. 99, R. 60 [11]	do	485	1¼	90	Flows.	
T. 99, R. 60	do	400-540	6-1¼	25-1	Flow.	Twelve wells.
T. 98, R. 60 [11]	do	559	2	50	Flows.	
T. 98, R. 59	do	400-450	2-1¼	15-1	Flows.	Six wells.
T. 99, R. 59	do	490	2		Flows.	
T. 98, R. 60	do	475-580	5-2	120-10	Flow.	Fifteen wells.
T. 98, R. 61	do	500-738	3-1¼	40-13	Flow.	Nine wells.
T. 97, R. 60	do	550-614	4¼-1¼	50-40	Flow.	Three wells, not including town well at Tripp.
T. 97, R. 61	do	945			Flows.	
T. 97, R. 59	do	517-550	2-1¼	30	Flow.	Two wells.

[1] Record, U. S. Geol. Surv., 17th Ann. Rept., part 2, pp. 46-50.
[2] Analysis, U. S. Geol. Surv., 21st Ann. Rept., 1899-1900, part 4, p. 570.
[3] Ibid., pp. 568, 571.
[4] Ibid., p. 573.
[5] Record, U. S. Geol. Surv., 17th Ann. Rept., part 2, p. 22.
[6] Ibid., p. 26.
[7] Ibid., pl. 84.
[8] Record, U. S. Geol. Surv., 18th Ann. Rept., part 4, p. 579.
[9] Record, U. S. Geol. Surv., 17th Ann. Rept., part 2, pl. 76.
[10] Ibid., pp. 47-48.
[11] Record, U. S. Geol. Surv., 18th Ann. Rept., 1897, part 4, pp. 580-585.

SOUTH DAKOTA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
T. 97, R. 57, sec	Hutchinson	500-406	2-1¼	2	Flow.	Two wells.
T. 97, R. 57	do	747-485	2-1¼	4-3	Flow.	Do.
T. 97, R. 56	do	445	2		Flows.	
Highmore[1]	Hyde	1,552	6	9	+ 35	Temp. 72°.
T. 108, R. 64, sec. 11	Jerauld	799	2-1¼	2	Flows.	
T. 108, R. 65, sec. 5[2]	do	1,057	2¼	200	+207	
T. 106, R. 63, sec. 2	do	715	2	200	+304	
T 106, R. 63, sec. 6	do	760	3-2	280	+253	
T. 106, R. 64, sec. 9[2]	do	880	2¼	280	+262	
T. 106, R. 64, sec. 17	do	810	2¼	5	Flows.	
T. 106, R. 64, sec. 15	do	816	3	10	Flows.	
Desmet	Kingsbury	1,610				
Arlington	do	800			No flow.	
Iroquois[3]	do	1,115	4¼	1,000	+154	
T. 109, R. 58, sec. 30	do	600	2		Flows.	
Britton[4]	Marshall	1,004	8-3¼	600	+365	Temp. 64°.
Langford	do	1,050	6	400-500	+138	
Newark	do	940	8-6	600	+288	Water at 420, 480, and 900 feet.
Rosebud Agency (26 miles northeast).	Meyer	2,500	8-6		−600	
Gettysburg	Potter	2,140			−100	
Artesian (1 mile southwest).[5]	Sanborn	±630	3		+ 81	
Letcher[6]	do	577	3-2	90	+207	Water at 300, 400, and 570 feet.
T. 105, R. 61, sec. 23[6]	do	561		125	Flows.	
T. 105, R. 61, sec. 15[6]	do	578	2	70	Flows.	
T. 107, R. 62, sec. 29	do	742	3	425	+299	
T. 105, R. 62, sec. 26	do	445	2-1	3	Flows.	
T. 105, R. 60, sec. 10	do	625	2	30	Flows.	
T. 105, R. 60, sec. 20	do	497	2	165	Flows.	
T. 105, R. 62, sec. 19	do	485	2	4	Flows.	
T. 105, R. 62, sec. 17	do	463	2	6	Flows.	
T. 105, R. 62, sec. 30	do	500	1¼	15	Flows.	
T. 105, R. 60, sec. 14	do	511	2	100	Flows.	
T. 105, R. 61, sec. 15	do	584	2	80	Flows.	
T. 105, R. 60, sec. 27	do	445	2	30	Flows.	
Woonsocket[6]	do	725	6	1,150	+299	
Do	do	775		Many.	+288	
Ashton	Spink	1,003	8	2,000	+345	
Do.[7]	do	925	6-4¼	100	+138	Flows at 650, 795, and 900 feet.
Conde	do	960	4¼	Many.	Flows.	
Doland[7]	do	897	4¼	370	+281	
Do	do	957		600	+258	
Frankfort[7]	do	1,008	8-4¼	Many.	Flows.	Flows at 803, 864, 945 and 1,000 feet.
Mellette	do	1,065	8-6	1,200	Flows.	
Do.[7]	do	920	6-4¼	1,320	+380	
Northville	do	980	9-6	1,900	+359	Flows at 875 and 956 feet.
Redfield[7]	do	964	6¼ 4¼	1,260	+407	
Do	do	1,025	6	1,900	Flows.	
Turton	do	920	4¼	1,300	Flows.	
T. 119, R. 63, sec. 22[7]	do	958		60	+324	
T. 119, R. 63, sec. 19[7]	do	930	4¼	670	+352	
T. 119, R. 64, sec. 23[7]	do	903	6-4¼	1,300	+311	
T. 119, R. 63, sec. 32[7]	do	920	4¼-3	2,894	Flows.	
T. 117, R. 64, sec. —[7]	do	987		Many.	Flows.	
T. 117, R. 62, sec. 32	do	950	4¼	350	Flows.	
T. 116, R. 62, sec. 4	do	895	4¼	600	Flows.	
T. 115, R. 61, sec. 7	do	1,050	8-4¼	75	+200	
T. 114, R. 63, sec. 26[7]	do	909		1,200	Flows.	
T. 114, R. 62, sec. 18[7]	do	1,000	6-4¼	150	+288	
T. 114, R. 63, sec. 32[7]	do	1,150	6 4¼	550	+115	
T. 114, R. 62, sec. 30	do	909	4¼	1,000	+345	
Fort Randall[8]	Todd	610	4	600	Flows.	
Yankton (Excelsior Mill).	Yankton	493	8	3,000	+120	
Yankton (Fountain Mill).[9]	do	600	6	1,500	+110	
Yankton (Asylum)[9]	do	672	4¼	165	+28	
Yankton (city well)[9]	do	942	6	880	+41	

[1] Record, U. S. Geol. Survey, 17th Annual Report, part 2, p. 24.
[2] Ibid., pp. 29-30.
[3] Ibid., pp. 22-23.
[4] Ibid., p. 181.
[5] Record, U. S. Geol. Surv., 18th Annual Report, 1897, part 4, p. 575.
[6] Records, U. S. Geol. Surv., 17th Annual Report, 1896, part 2, pp. 31-33.
[7] Ibid., pp. 19-20.
[8] Ibid., p. 58.
[9] Record, U. S. Geol. Surv., 17th Annual Report, 1896, part 2, pp. 53, 58.

SOUTH DAKOTA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Yankton (College Hill).	do	524	2	2,600	+62	
Yankton (Wilcox well).	Yankton	455	3	330	+127	
Yankton (Donaldson well).	do	525	4½		Flow.	
T. 93, R. 56, sec. 12	do	475	2	6	Flow.	
T. 93, R. 56, sec. 17	do	400	2	500	Flow.	
T. 93, R. 56, sec. 16 [1]	do	500	6-5	1,300	+115	
T. 93, R. 55, sec. 8	do	521	3	350	+113	
T. 93, R. 54, sec. 18 [1]	do	422	3½-3	120	Flow.	
T. 94, R. 55, sec. 19 [1]	do	648	2	4	Flow.	
T. 93, R. 54, sec. 11	do	450	2	80	Flow.	
T. 94, R. 55, sec. 18	do	480	2	55	+23	
T. 94, R. 55, sec. 22	do	522	2	30	Flow.	
T. 94, R. 55, sec. 21	do	435	2	100	Flow.	
T. 94, R. 54, sec. 36	do	495	2	75	Flow.	
T. 95, R. 55, sec. 8	do	535	2	50	Flow.	

PUBLICATIONS RELATING TO DEEP BORINGS IN SOUTH DAKOTA.

Report on Irrigation, 52d Congress, 1st session, Senate Ex. Doc. No. 41, part 2, pp. 40-65, Washington, 1893.

Preliminary Report on the Artesian Waters of a Portion of the Dakotas, by N. H. Darton, United States Geological Survey, Seventeenth Annual Report, 1895-96, part 2, pp. 609-694, Washington, 1896.

New Development in Well Boring and Irrigation in South Dakota, by N. H. Darton, United States Geological Survey, Eighteenth Annual Reports, 1896-97, part 4, pp. 567-615, Washington, 1897.

Geology and Water Resources of a portion of Eastern South Dakota, by J. E. Todd, United States Geological Survey, Water-Supply and Irrigation Papers, No. 34, 34 pages, plates and maps, Washington, 1900.

TENNESSEE.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Bells	Crockett	1,100				Prospect well; unsuccessful.
Chattanooga	Hamilton	600	10-8	50	-45	
Crockett Mills	Crockett	+900	3		No flow.	Abandoned.
Dull (2 miles from)	Dickson	565	4½			Three oil wells.
Do	do	2,000	4½			Oil well.
Dyersburg [2]	Dyer	600		140	Flows.	Do.
Do	do	600		130		Do.
Glen Mary (2 miles west). [2]	Scott	1,238-1,340				Oil wells; several others in Scott County.
Do	do	600				
Helenwood(?)	do	1,500				For oil; unsuccessful.
Hurricane Creek [2]	Union(?)	530				Oil well.
Iron City	Lawrence	400	12			For oil or gas.
Do	do	480				For gas; not in use.
Kingston Springs	Cheatham	1,000				Unsuccessful.
Knoxville	Knox	2,100				Temp. 57°.
Memphis	Shelby	450-400	8-6	200-100		Several wells.
Do. [4]	do	+1,156				
Do	do	3,000-2,000				Several wells for oil; abandoned.
Rugby	Morgan					Several wells for oil.
Saltillo	Hardin	950	36-6	Many.	Flows.	Sulphur; temp. 45°; bored in 1830.
Tullahoma	Coffee	700				Oil well.

[1] Record, U. S. Geol. Surv., 17th Annual Report, 1896, part 2, pp. 53,58.
[2] Tennessee, Comm'r Ag. Rept., Oil Region, 1877, pp. 54, 73.
[3] U. S. Geol. Surv., 17th Ann. Rept., 1895-96, part 3, pp. 699-700.
[4] Tennessee, State Board of Health, Bulletin, vol. 5, 1890, pp. 98-106.

TEXAS.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Abbott (1½ miles N.)	Hill	446		20	−160	
Do	do	486		Several.	−186	
Abilene	Taylor	2,500				
Albany	Shackelford	400		Few.		
Alta Loma	Galveston	875-950	9	310	22	Numerous wells. Temp. 75°-78°.
Alvarado	Johnson	1,500			Flows.	
Alvin (4 miles north)	Brazoria	502	2	70		
Aquilla	Hills	600		Few.	Flows.	
Do	do	800		Several.	Flows.	
Archer City	Archer	550	6	Few.	−50	Alkali water.
Do.[1]	do	736			No flow.	
Do	do	500				Salt water only.
Arcola	Fort Bend	±910		300	Flows.	
Argyle (1½ miles east)	Denton	500			Flows.	Soft water.
Arlington	Tarrant	1,480		21		Strong mineral water.
Aul[2]	Bexar	673			−4	
Austin (Fifth and Jacinto streets).[3]	Travis	2,020		175	Flows.	
Austin (asylum)	do	1,280				
Austin (poorhouse)	do	1,300		5	No flow.	
Austin	do	471		5		
Do	do	1,450		5		
Austin (East Fifth street).	do	700		14	Flows.	In progress 1897; sulphur water.
Austin (Natatorium)[4].	Travis	2,025	10-8-7-6	175	Flows.	Main flow at 1,875 feet; temp. 100°.
Austin (Asylum)[4]	do	1,975		+104	+40	
Austin[4]	do	2,053			−5	
Do	do	1,280				
Austin (near)	Kinney	400				Several wells.
Baileyville	Milan	800				Failure.
Baileyville (3 miles west).	do	831			No flow.	Water very salty.
Baird	Callahan	415	8			Abandoned.
Bastrop	Bastrop	+900				No water.
Barstow	Ward	+500			No flow.	
Batesville	Zavalla	700			−300	
Bedford (2 miles S.)	Tarrant	602½			Flows.	Soft water.
Belcherville	Montague	900-1,200		70	Flow.	Three wells; soft water.
Belton (9 miles W.)	Bell	700			Flows.	
Belton (10 miles SE.)	do	1,800		Many.	Flows.	
Belton (2 miles NE.)	do	1,000			Flows.	
Belton (19 miles W.)	do	530			Flows.	
Belton (9 miles SW.)	do	772		70	Flows.	
Belton[5]	do	975	4	173.6	Flows.	Soft water.
Belton (1 mile SW.)	do	1,060		347	Flows.	Do.
Belton (1 mile S.)	do	1,000			Flows.	
Big Spring	Howard	603	7			Salt water at 300 feet; abandoned.
Birdville	Tarrant	406			No flow.	Soft water.
Birdville (1 mile N.)	do	486			−20	Do.
Birdville (one-half mile from).	do	420		Many.	Flowed once.	
Blum (4½ miles E.)	Hill	532			−200	
Bolivar	Denton	1,176			Flows.	
Bonham	Fannin	+400				
Do	do	+400				
Do	do	1,500				No water.
Bowie	Montague	700			−160	
Bowie (one-half mile west).	do	600				
Boyce (1½ miles west)	Ellis	981		1½	Flows.	Soft water.
Do	do	975			Flows.	Do.
Brackettville (7 miles from).[6]	Kinney	404		Several.		
Brambleton	Tarrant	485			−130	Do.
Branchville (4 miles east).	Milan				Flows.	
Do	do	700			−6	
Breckenridge	Stephens	1,400				Failure.

[1] Record, 51st Congress, 1st session, Senate Ex. Doc. No. 222, p. 262, Washington, 1890.
[2] Record, U. S. Geol. Surv., 18th Ann. Rept., 1896-97, Part II, p. 272, Washington, 1898.
[3] Ibid., pp. 280-283.
[4] U. S. Geol. Surv., 18th Ann. Rept., 1896-97, Part II, pp. 280, 284, Washington, 1898.
[5] Record, Artesian waters of Texas west of the 97th meridian, by R. T. Hill, 52d Congress, 1st session, Senate Ex. Doc. No. 41, part 3, p. 116, Washington, 1893.
[6] Record, U. S. Geol. Surv., 18th Ann. Rept., 1896-97, part 2, p. 278, Washington, 1898.

TEXAS—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Bremond	Robertson	1,500			No flow.	Some water.
Brenham	Washington	600				Failure.
Brownville (50 miles northwest).	Hidalgo	70			No flow.	
Brownwood (northeast of).	Brown	1,900				Oil borings; some gas.
Brownwood	do	1,938	10-6	32	+74	
Do	do	1,558				Failure.
Do	do	1,803				Do.
Bruceville	McLennan	1,560	6		+125	
Do	do	1,565		139	Flows.	Soft water; temp. 95°.
Bryan (16 miles south).	Burleson	870	2	22	Flows.	
Bryan (12 miles from)	do	835	2	35	+30	Temp. 85°.
Do	do	635	2	22	+25	Temp. 76°.
Do	do	550	7	15	+20	Do.
Burke	Angelina	500				Salt water; abandoned.
Burleson (1 mile west).	Johnson	500			No flow.	Soft water.
Burleson (2½ miles west).	do	465		Many.	No flow.	Do.
Call	Newton	700		Several.	Flows.	
Calvert [1]	Robertson	460			−30	
Do.[2]	do	585-620	4	Many.	Flow.	Several wells.
Calvert (5 miles southwest).	do	510	1	Many.	Flow.	Several wells in vicinity.
Do	do	900	1		−20	
Calvert (5 miles west)	do	400			−20	
Do	do	800			−100	
Cayote (3 miles northeast).	Bosque	439			No flow.	
Cedar Bayou	Harris	558	3			
Do	do	600	3		Flows.	
Do	do	727	3	5	Flows.	Temp. 76°.
Do	do	610	3	30		Do.
Cedar Hill (19 miles southwest).	Dallas	750		Many.	−300	Soft water.
Celina	Collin	470		7.7	−145	Do.
Celina (1 mile west)	do	400			−100	Do.
China Springs	McLennan	1,380			Flows.	Another flow at 800 feet; temp. 102°.
Do	do	1,100		40	Flow.	Two (?) wells.
Cisco	Eastland	1,680	8		−25	Salt water.
Clarksville	Red River	1,060			Flows.	Brackish water; abandoned.
Do	do	+1,050			−10 to −12	Salty water.
Do	do	+1,200				Abandoned.
Cleburne	Johnson	970-1,003		70	−40 to −70	Many wells.
Cleburne (6 miles south).	do	520		Many.	No flow.	Soft water.
Cleburne (5 miles southeast).	do	568			−168	Do.
Cleburne (3 miles southwest).	do	420		Many.	−160	Do.
Cleburne (3 miles northwest).	do	424		Many.	−274	
Clifton	Bosque	640		170	Flows.	
Do	do	700		Many.		Temp. 70°.
Clifton (3 miles N.)	do	662		220	Flows.	Temp. 84°; soft water.
Clifton (1 mile west)	do	715		60	Flows.	Soft water.
Clifton (3½ miles N.)	do	670		170	Flows.	
Clifton (8 miles SE.)	do	840		170	Flows.	
Clifton (3 miles W.)	do	612			Flows.	Do.
Clifton (1 mile W.)	do	687			Flows.	Do.
Clifton	do	700		Many.		Temp. 70°.
Clifton (three-fourths mile west).	do	700		11	Flows.	Soft water.
Colorado[3]	Mitchell	1,120				Several deep salt wells.
Commerce	Hunt	2,300				
Comstock (20 miles from).[4]	Valverde	569				

[1] Record, 51st Congress, 1st session, Senate Ex. Doc. No. 222, p. 266, Washington, 1890.
[2] Record, Texas Geol. Surv., 4th Ann. Rept., 1892, p. 109.
[3] Record, U. S. Geol. Surv., 18th Ann. Rept., 1896-97, Part II, p. 265, Washington, 1898.
[4] Record, 51st Congress, 1st session, Senate Ex. Doc. No. 222, p. 284, Washington, 1890.

TEXAS—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Coperas Cove	Coryell	1,865			−100	Brackish water.
Coperas Cove (4 miles north).	do	500		Many.	No flow.	Salty water.
Coperas Cove	do	1,875			−475	
Cornhill	Williamson	404			−282	
Corpus Christi	Nueces					
Do	do	1,765		50		Mineral water at about 600 feet only.
Do	do	525		300		
Do	do	560		100		
Corsicana	Navarro					
Corsicana (3 miles west).	do	2,500				
Corsicana	do	2,477				Several wells.
Do	do	1,000-1,200				Many oil wells.
Do	do	2,483		208	+150	Water, gas, and oil; temp. 126°.
Do	do	2,150		208		Oil at 1,100 feet.
Do	do	2,487		Many.		
Do	do	2,500		+194.4	+85	Temp. 126° F.
Do	do	1,035				Oil well.
Corsicana (3 miles west).	do	2,300				
Coryell (3 miles east)	Coryell	940		Many.	−50	Soft water.
Cotulla[1]	Lasalle	825			Flows.	Bad water.
Do	do	1,010		55.5		
Do	do	852				
Do	do	800		2	Flows.	Do.
Do	do	1,008		Many.	+6	Temp. 86° F.; alkaline-saline water.
Cotulla (8 miles S.)	do	600			−100	Bad water.
Crawford (4 miles west).	McLennan	1,000		31		Soft water.
Do	do	1,040		31		Do.
Do	do	945		140		Temp. 72° F.; two wells.
Do	do	1,060		50		Soft water.
Crockett	Houston	630	5-3	Many.	−190	
Crowley	Tarrant	486		3	No flow.	Soft water.
Crowley (3 miles northwest).	do	446			−150	Do.
Crowley (7 miles southwest).	do	430			No flow.	Do.
Crowley (2 miles from).	do	484	2		−134	Do.
Cyrus (1 mile east)	Bosque	1,000		Many.	Flows.	
Dallas (1 mile east)	Dallas	850		70	Flow.	Two wells.
Dallas (6 miles west-northwest).	do	+400		Many.	Flows.	
Dallas	do	790-1,000		Many.	Flows.	Numerous wells.
Do	do	718			Flows.	Much soda in water.
Do	do	700		12	Flows.	
Dallas (City Park)	do	672		15	Flows.	
Dallas	do	±2,500				
Dallas (1 mile south)	do	850		70	Flow.	Two wells.
Dallas (6 miles west-northwest).	do	±400		Many.	Flows.	
Davenport	Guadalupe	810			−180	Good water.
Del Rio[2]	Valverde	760			−60	Mineral waters.
Del Rio (30 miles N.)	do	475			−300	
Del Rio (3 miles S.)	do	460			Flows.	Sulphur water.
Denison (1 mile S.)[3]	Grayson	1,800	2¼			Abandoned.
Denton	Denton	460			+15	
Do	do	550	6	6	+20	
Do	do	600		Few.		
Do	do	620		8	Flows.	
Do	do	600			Flows.	
Do	do	606		28	Flows.	
Derby	Frio	540		Many.	−35	
Dickinson[4]	Galveston	600	3	14	Flows.	
Do	do	624	3	40	Flows.	
Dickinson (3 miles W.)	do	700	3	34.7	Flows.	
Dickinson (one-fourth mile west).	do	588	1		Flows.	
Dryden	Pecos	1,797	7¼-4	18	−600	

[1] Texas, Geol. Surv., 2d Ann. Rept., 1891, p. 71; Analysis, 51st Congress, 1st session, Senate Ex. Doc. No. 222, p 272, Washington, 1890.
[2] U S. Geol. Surv., 18th Ann. Rept., 1896-97, Part II, pp. 265, 299, Washington, 1898.
[3] Record, ibid., 21st Annual Report, 1899-1900, part 7, p. 197, Washington, 1901.
[4] Analysis, Texas Geol. Surv., 4th Ann. Rept., 1892, p. 104.

TEXAS—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Dryden	Pecos	590		Many.	-530	
Dublin	Erath	400			−8	
Eagleflat	El Paso	680				No water.
Eagleford	Dallas	417		800	+35	Soft water.
Eagle Pass[1]	Maverick	1,508				Salty water.
Do	do	400				Abandoned.
Eastland[2]	Eastland	500				Abandoned.
Do	do	1,300	6		No flow.	Salt water.
Do	do	400			Flows.	Mineral water.
Eden	Concho	987		7	Flows.	Salty water.
Do	do	800				Oily water; abandoned.
Eddy	McLennan	1,565		208	Flows.	Soft water.
El Paso (NW. of)	El Paso	800				In granite; no water.
El Paso (10 miles NE.)[3]	do	621			−215	
Encinal	Webb	900			−200	Good water.
Enon	Tarrant	442			−142	
Enon (1 mile west)	do	430		5	−60	
Enon (3 miles NE.)	do	460		Many.	−90	Soft water.
Estelle	Dallas	970			Flow.	Soft water.
Eulogy	Bosque	780		34	Flows.	
Do	do	520		30	Flows.	
Eulogy (1 mile north)	do	475			Flows.	Do.
Eulogy (three-fourth mile north)	do	460		10	Flows.	
Eulogy (one-fourth mile west).	do	430		68	Flows.	Do.
Fairwood[4]	Galveston	575	3	50	Flows.	Temp. 78½°.
Farr (2 miles south)	McLennan	1,065		10	Flows.	
Ferris	Ellis	1,380		89	Flows.	
Finlay[5]	El Paso	1,080	8			Bad water at 396 feet; abandoned.
Forreston	Ellis	400				No water.
Fort Bliss Station		403	4½	Many.	−130	
Fort Worth[6]	Tarrant					
Do	do	484			−50	
Do	do	450				
Do	do	465		30	Flows.	
Do	do	950-1,400	10 to 4	140	Flow.	Several wells.
Do	do	4,000				No flow below 1,200 feet; temp. 140° at 3,250 feet.
Do	do	760				
Fort Worth (3 miles north).	do	1,200				
Fort Worth (10 miles east).	do	480	4½	+208		
Fort Worth (12 miles southeast).	do	534			−450	
Fort Worth (7 miles south).[7]	do	+400				
Fowler (1½ miles N.)	Bosque	735		123	Flows.	Soft water.
Frankfort (2 miles southwest).	Collin	442			−50	Salty water.
Franklin	Robertson	1,200			No flow.	
Freeland (2 miles S.)	Johnson	500		15	Flows.	Soft water.
Freeland (2½ miles S.)	do	618		18	Flows.	
Freeland (1½ miles S.)	do	585		65	Flows.	Good water.
Freeland (1½ miles W.)	do	548		12	Flows.	Soft water.
Gainesville	Cooke	±1,250			−40	In progress.
Do	do	850		243	−10	
Do	do	480			−40	
Do	do	405		69	No flow.	
Do	do	632		Many.	−7	
Do	do	700			−30	
Do	do	850		6		
Galveston[8]	Galveston	3,070	22-6	Many.	Flows.	Brackish water at various depths to bottom.
Do	do	1,346		400	Flows.	Salty water.

[1] Record, 51st Congress, 1st session, Senate Ex. Doc. No. 222, p. 266, Washington, 1890.
[2] Ibid., pp. 268, 269.
[3] Record, 51st Congress, 1st session, Senate Ex. Doc. No. 222, p. 297, Washington, 1890.
[4] Analysis, Texas Geol. Surv., 4th Ann. Rept., 1892, p. 102.
[5] Analysis, 51st Congress, 1st session, Senate Ex. Doc. No. 222, p. 272, Washington, 1890.
[6] Record, Artesian Waters of Texas west of 97th meridian, by R. T. Hill, 52d Congress, 1st session, Senate Ex. Doc. No. 41, Part 3, pp. 105-106, Washington, 1893.
[7] Fifty-first Congress, 1st session, Senate Ex. Doc. No. 222, p. 270, Washington, 1890.
[8] Records, analysis, etc., Texas Geol. Surv., 4th Ann. Rept., 1892, pp. 87-101; U. S. Geol. Survey, 21st Annual Report, 1899-1900, part 7, pp. 402-406, Washington, 1901.

TEXAS—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet	*Inches.*	*Gallons.*	*Feet.*	
Galveston	Galveston	810-973		Many.	Flow.	Several wells; water too salty.
Galveston (2½ miles west).	do	1,365		250	Flows.	Temperature 84°.
Gatesville	Coryell	500-550	6	2-20	Flow.	Several wells.
Do	do	700		175		
Do	do	475			No flow.	Soft water.
Gatesville (8 miles W.)	do	612				Do.
Gatesville (6 miles southeast).	do	558		4	Flows.	
Georgetown (2 miles east).	Williamson	520		15		
Godley (5 miles S.)	Johnson	420		Many.	No flow.	Do.
Goldthwaite	Mills	563	10-7		− 20	
Do	do	600				
Do	do	563	10-7		− 20	
Gonzales	Wilson	1,400		15	+ 60	Flows at 650, 950, 1,300, and 1,400 feet.
Do	do	625	10-8	30	Flows.	
Gonzales (1 mile N.)	do	1,135		Many.	− 60	
Gordon	Palo Pinto	485		1	+ 23	Salt water.
Do	do	498	1	1	+ 23	Salt water and gas.
Grapevine	Tarrant	423			No flow.	Soft water.
Gravis (1½ miles S.)	Williamson	412		3	−96	Sulphur water.
Greenway (one half mile west).	Johnson	590		45		Soft water.
Greenway (one-half mile northwest).	do	602		22	Flows.	Do.
Hamilton	Hamilton	425				Water only at 350 feet to −8 feet.
Handley	Tarrant	509			−25	Soft water.
Hallettsville	Lavaca	300-560			Flow.	
Harmosa	McLennan	1,730		139		Soft water; temp. 103°.
Hartley	Hartley	410	5	17		
Haskell	El Paso	2,029	12-7¼	Few.	No flow.	
Haslett (1 mile S.)	Tarrant	430			−255	Soft water.
Haslett (3 miles SE.)	do	480		3	−258	
Hearne	Robertson	740			Flows.	Many wells in vicinity.
Do	do	400-450	4		Flow.	Several wells.
Do	do					
Do	do	450-700	2	3 to 10	+10-+40	Do.
Hearne (8 miles S.)	do	300-700		3	Flows.	
Hearne (12 miles northwest).	do	300-700		3	Flows.	
Heffron	Galveston	480	3	52	+16	Temp. 80° ±
Hemming	Cooke	426		100	Flows.	Soft water.
Hico	Hamilton	1,365	12		−125	Water at 210, 300, 600, and 900 feet.
Do	do	1,200			No flow.	
Hidalgo	Hidalgo	700			−100	
Hillsboro	Hill	1,800			Flows.	
Do	do	1,762		34.7	Flows.	
Do	do	500				Failure.
Hitchcock[1]	Galveston	726		66	Flows.	Temp. 77°; many wells in vicinity.
Hitchcock (1½ miles northwest).	do	710		100	Flows.	Temp. 77°.
Do	do	768		48	Flows.	Temp. 78°.
Holland (10 miles S.)	Bell	1,800		10	Flows.	Salt water.
Honeygrove	Fannin	1,700		Many.		Strong mineral water.
Do	do	1,650		Many.	− 50	Do.
Do	do	1,500				
Do	do	1,000			−300	Salty water; not in use.
Do	do	1,200			No flow.	
Hondo	Medina	1,000				No water.
Do	do	1,500		Many.	−175	
Houston	Harris	493	8	120	Flows.	
Do	do	564	8	130	Flows.	
Do	do	850	5	200	Flows.	
Do	do	500 or less.			Flows.	Fine water.
Do	do	700				
Houston (3 miles from).	do	600		42		Temp. 70°.
Hubbard	Hills	3,166			Flows.	

[1] Analyses, etc., Texas Geol. Surv., 4th Ann. Rpt., 1892, pp. 102-103.

TEXAS—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Hueco	El Paso	431				Bad water; abandoned.
Hueco (20 miles NNE.)	do	572		Many.		Bad water.
Humble	Harris	600	3½	50	Flows.	Fresh water.
Huntsville	Walker	2,210	9-3	Many.	−100	
Hurst Lake	Coryell	500				
Italy	Ellis	1,400		¼	− 10	Soft water.
Itasca	Hills	1,800			Flows.	
Do	do	1,680		160	+ 35	
Jefferson	Marion	802		Few.	Flows.	Sulphur water.
Joshua (3 miles west)	Johnson	525			No flow.	Soft water.
Joshua (6 miles NW.)	do	424			−189	
Kaufman	Kaufman	450				Failure.
Kaufman (1 mile NW.)	do	600				Do.
Kearnes	Kearnes	1,800				Do.
Keechi	Jack	400		1/20	−400	Soft water.
Keene	Johnson	750			−300	Do.
Keller	Tarrant	400				
Do	do	457		50	−50	
Do.[1]	do	430				
Keno	Liberty	700				No water below 90 feet; abandoned.
Kerrville	Kerr	1,325			−75	Good water at 750 feet.
Kerrville (9½ miles northeast).[2]	do	1,100		Several.	−55	Granite below 180 feet.
Killeen	Bell	606			−60	
Kimball	Bosque	550-630			Flow.	Several wells.
Kimball (6 miles west)	do	564		60	+20	Soft water.
Kopperl	do	400		¼	Flows.	
Kopperl (½ mile east)	do	600		800	Flows.	Do.
Kopperl	do	625		150	Flows.	Slightly brackish.
Kopperl (3½ miles W.)	do	600		200		
Kopperl	do	525			Flows.	
Krum (2½ miles south)	Denton	450			No flow.	
Ladonia	Fannin					
Do	do	1,033				Never completed.
Lancaster	Dallas	1,057			Flows.	Soft water.
Lanham	Hamilton	470				Abandoned.
Do	do	500				Do.
Do	do	600				
Lanoria[3]	Mesa	621			−215	
Laporte	Harris	454	3	41	Flows.	
Do	do	440	3	80	Flows.	
Laredo	Webb	1,200			No flow.	
Lebanon	Collin	400		Many.	−100	
Llano (9 miles SE.)	Llano	500			+2	Coal prospect; abandoned.
Longfellow	Pecos	683	8	20	No flow.	
Lorena	McLennan	1,495		Many.	Flows.	Soft water.
Lorena (5 miles west)	do	760		Few.	Flows.	Salt water.
Lorena	do	1,495		Many.	Flows.	Soft water.
Lozier	Pecos	770	7½	Few.	No flow.	
Lufkin	Angelina	1,300				No water; abandoned.
Manor[4]	Travis	2,220	6	69	+30	Temp. 93°.
Marine (½ mile NE.)	Tarrant	1,200		545	Flows.	Temp. 78°; soft water.
Marlin	Falls	3,350		140	+322	Temp. 147°.
Marshall	Harrison	1,000			No flow.	
Maxon Springs	Buchel	1,004	9½-4½	Several.		Not in use.
Maysfield	Milam	1,356	4	Many.	−34	
McGregor	McLennan	1,030		139	−10	Soft water.
Do	do	470			Flows.	
Do	do	991		348		
McGregor (5 miles west.)	do	490		Many.	−11	Do.
McKinney	Collin	1,860		21	−70	Soft water.
Menardville (near)	Brown	1,100				Found water, etc., but well now caved in.
Menardville	Menard	1,175				Oil boring unsuccessful.
Meridian	Bosque	450-580		25-45	Flow.	Several wells; soft water.
Meridian (10 miles E.)	do	850		16	Flows.	
Meridian (12 miles E.)	do	875			−42	Soft water.

[1] Record. Artesian waters of Texas west of 97th meridian, by R. T. Hill, 52d Congress, 1st session, Senate Ex. Doc. No. 41, Part 3, p. 104, Washington, 1893.
[2] U. S. Geol. Surv., 18th Ann. Rept., 1896-97, Part II, p. 271, Washington, 1898.
[3] Record, 51st Congress, 1st session, Senate Ex. Doc. 222, p. 297.
[4] Record, U. S. Geol. Surv., 18th Ann. Rept., 1896-97, Part 2, pp. 285-286, Washington, 1898.

TEXAS—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Merkel	Taylor	+2,000				
Miami	Roberts	—500				Several wells in county.
Midlothian	Ellis	464			—200	
Milford	do	2,018			Flows.	Mineral water?.
Mineola[1]	Wood	1,200	6-3		—40	
Moody	McLennan	1,508		69	No flow.	Soft water.
Do	do	1,300			No flow now.	
Do	do	1,450			—15	
Morgan[2]	Bosque	600		100	Flows.	Soft water.
Do	do	580-620		20-150	Flow.	Several wells; soft water.
Morgan (1 mile SE.)	do	575		170	Flows.	Soft water.
Morgan	do	800		50	Flows.	
Morgan (5 miles east)	do	780		40	Flows.	
Morgan (12 miles E.)		501		100	Flows.	
Morris Ranch[3]	Gillespie	1,100			—55	
Mound (2 miles NE.)	Coryell	697			—5	Mineral water.
Mountain Peak (¼ mile southwest).	Ellis	435		Many.	No flow.	Soft water.
Mumford	Robertson	300-1,000		2-12		Several wells.
Myers	Burleson	440	1-2	2		Temp. 60°.
Do	do	860	4 2	30	+20	Temp. 90°.
Myrtle Springs	Van Zandt	650				Unsuccessful.
Navasota[4]	Grimes	830			To surface.	
Navasota (16 miles N.)	do	999		Many.	Flows.	
Newlin Station	Hall	550	6			Four layers of salt water; abandoned.
Neri (2 miles south)	Hood	415			No flow.	Soft water.
Newark	Wise	410	5	1	+14	Temp., 65°.
New Boston	Bowie	1,200			—75	
Norse (4 miles SW.)	Bosque	622			No flow.	Soft water.
North Galveston	Galveston	575-1,500	3	70 each.	Flow.	Several wells.
Oak Grove (1 mile S.)	Tarrant	500		3½	—72	Soft water.
Ocee (1 mile east)	McLennan	1,098	6	160	Flows.	Do.
Odessa	Ector	830	8			Abandoned.
Oglesby (2½ miles northwest-west).[5]	Coryell	500			No flow.	Soft water.
Orphans' Home Station (2 miles SE).	Dallas	685			No flow.	Very salty water.
Orphans' Home Station.	do	1,230		20	—40	Mineral water.
Palestine	Anderson	650	6	Few.	—200	
Palestine (1½ miles)	do	444	8-6	121	No flow.	Several wells.
Palmer	Ellis	1,154		+ 9	Flows.	Soft water.
Do	do	1,154			Flows.	Do.
Do	do	1,178		83	Flows.	Do.
Panhandle City	Carson	600				Unsuccessful.
Paris	Lamar	444				Abandoned.
Do	do	1,350		Many.	—5	
Park Springs	Wise	400	6	Many.	—60	
Pearsall	Frio	600		15	Flows.	
Do	do	400		30	Flows.	
Do	do	650		30	Flows.	
Do	do	620			—20	
Pearsall (15 miles E.)	do				Flow.	Several wells.
Pearsall (20 miles SE.)	do	(?)				
Pecangrove	Coryell	590			Flows.	
Pecos[6]	Pecos	683		20		
Do	do	987		28		Good water.
Do	do	1,797		16		Do.
Do	do	770		16		
Pecos (4 miles W.)	Reeves	400			No flow.	
Pierce Station	Wharton	850 or 900				
Pilotpoint	Denton	937		17	—25	Soft water.
Pilotpoint (8 miles northwest).	Cooke	426		1		Do.
Port Arthur	Jefferson	±800	5		Flows.	Mineral water; temp. 80°.
Pottsboro (7 miles west).	Grayson	±500		Many.	Flows.	Pure water.
Prosper	Collin	470		Many.	No flow.	Soft water.

[1] Geol. Surv. of Texas (Report on the Brown coal and lignite of Texas), pp. 132-135, 1892.
[2] Record, 51st Congress, 1st session, Senate Ex. Doc. No. 222, p. 269, Washington, 1890.
[3] Record, U. S. Geol. Surv., 18th Ann. Rept., 1896-97, Part II, p. 272, Washington, 1898.
[4] Record, 51st Congress, 1st session, Senate Ex. Doc. No. 222, p. 265, Washington, 1890.
[5] Record, 51st Congress, 1st session, Senate Ex. Doc. No. 222, p. 283, Washington, 1890.
[6] Record, etc., U. S. Geol. Surv., 18th Ann. Rept., 1896-97, Part II, p. 267, Washington, 1898.

TEXAS—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Prosper (¼ mile east)	Collin	660		4	−244	Soft water.
Quintana	Brazoria	650				
Randol (1 mile NE.)	Tarrant	546			−10	Sulphur water.
Randol (one-half mile southwest.)	do	525		156	Flows.	
Randol (3 miles SW.)	do	420		4	Flows.	Soft water.
Randol (one-half mile north).	do	505	4		Flows.	Do.
Refugio [1]	Refugio	853		104	Flows.	
Refugio	do	956		104	Flows.	
Do	do	1,000		347	Flows.	
Rendon (2 miles N.)	Johnson	535		Many.	No flow.	Do.
Riovista (1 mile NE.)	do	460		Many.	No flow.	Do.
Riovista (3 miles E.)	do	540			−176	Do.
Roanoke (west.)	Denton	476			−33	
Roanoke	do	400-600		40-50	Flows.	Several wells.
Roanoke (one-half mile south).	do	505			−16	
Rocksprings	Edwards	400		Many.	No flow.	Two wells.
Do	do	450		Many.	No flow.	Do.
Rogers	Bell	+1,600			Flows.	
Roundrock	Travis	400		1	No flow.	
Roundrock	Williamson	1,400			−4	
Rusk	Cherokee	620				Abandoned.
Sabinal	Walde	529				
Salado (5 miles SE.)	Bell	412			−397	
San Angelo	Tom Green	960				
San Antonio [2]	Bexar	822-1,200		55-200		Numerous wells.
Do	do	1,250				
Do	do	465		55		
San Antonio (1 mile west).	do	835		55		
San Antonio	do					
Do	do	870		861		
San Antonio (3 miles southeast).	do	1,100				Hot sulphur water.
San Antonio (3 miles south).	do	1,900		555		
San Antonio (6 miles southeast).	do	2,215				Water at 1,800 feet.
San Antonio (2 miles south).	do	1,900		555	−84	
San Antonio	do	500				Several wells.
Do	do	650-715		500-700		Do.
San Antonio (2½ miles northwest).	do	540				
San Antonio	do	630				
Do	do	750-780		1,000		Do.
Do	do	450				
Do	do	657		250		Do.
San Antonio (3 miles north).	do	583			−50	
Sanderson [3]	Pecos	987	7¼	30	No flow.	
Sanderson	do	2,000				No water.
San Marcos [4]	Hays	1,490		6	Flows.	Waters at 128, 191, 652, 1,178, 1,291, 1,345, and 1,475 feet.
Santa Tomas						
Sherman	Grayson	632				Fine water.
Do	do	915				
Do	do	2,500		Many.	−40	
Do	do	660				Several wells.
Sherman (18 miles N.)	do	480			No flow.	
Sierra Blanco [5]	El Paso	943	5¼	Many.	No flow.	Bad water.
Sonora	Sutton	480				Several wells.
Do	do	800				Oil.
South Bosque (3 miles west).	McLennan	450		1		
Spofford Junction	Kenney	1,700				Failure.
Stony (1½ miles south)	Denton	447		3	Flows.	Soft water.
Strong Junction	Harris	450	3	48	+9	
Sugarland	Fort Bend	600-1,550	3-4		Flow.	Several wells
Do	do	1,550	8-4	104	+9	
Surfside	Brazoria	1,070	4	215	Flows.	
Taylor	Williamson	1,400		104	Flows.	

[1] Records, 51st Congress, 1st session, Senate Ex. Doc. No. 222, pp. 266-267, Washington, 1890.
[2] Records, etc., U. S. Geol. Surv., 18th Ann. Rept., 1896-97, Part II., pp. 290-297, Washington, 1898.
[3] Record, U. S. Geol. Surv., 18th Ann. Rept., 1896-97, Part II, p. 274, Washington, 1898.
[4] Ibid., pp. 287-290.
[5] Record, 51st Congress, 1st session, Senate Ex. Doc. No. 222, p. 296, Washington, 1900.

TEXAS—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Taylor	Williamsom	2,800		27	Flow.	Two wells; poor water.
Do	do	1,500		15	+40	Several wells
Temple (1 mile west)	Bell	1,850		Many.	Flow.	Temp. 91°.
Do	do	1,800		Few.	Flows.	
Terrell [1]	Kaufman	2,200	8	70	−50	Good water.
Texas City	Galveston	725		+104	+16	
Do	do	900		+104	+16	
The Grove	Coryell	900		680	−13	
Thorndale	Milan	1,790				No water.
Do	do	3,200				Do.
Thurber [2]	Erath	3,050			No flow.	
Tilden	McMullen	475	4¼	8	Flows.	Salty water.
Timber	Tarrant	576		2¼		Do.
Tobey	Atascosa	1,200-1,300				
Torbert	El Paso	1,100	8-5¼			Abandoned. Small amount of fair water at 696 feet.
Toyah	Reeves	834	9-3	300	Flows.	Sulphur water.
Do	do	514	12	9	Flows.	
Trinity	Trinity	+900		Few.		Salty, sulphur water
Trinity Mills (4 miles east).	Dallas	+468			−25	
Do	do	415			−25	
Troy	Bell	1,472	8		Flows.	Soft water.
Do	do	1,474		14	Flows.	
Do	do	1,464		243	Flows.	Do.
Turtle Bayou	Chambers	850	4	139	Flows.	
Do	do	900	4			
Tyler	Smith	1,150	6			In progress, 1901.
Uvalde	Uvalde	512		Few.	−85	
Do	do	1,000			No flow.	
Valda	Polk	420	4	45	Flows.	
Valentine	Presidio	1,280				No water.
Do	Jeff Davis	1,245	5¼-3	Many.	No flow.	
Valeo	Hidalgo	1,004	8			No water below.
Valley Mills	Bosque	805			Flows.	
Valley Mills (5 miles north).	do	870			Flows.	Soft water.
Valley Mills (1 mile north).	do	706			Flows.	
Valley Mills (5 miles north).	do	877			Flows.	Do.
Van Horn	El Paso	600	5¼		−500	Several wells.
Velasco	Brazoria	1,100	8	694	Flows.	
Vernon [3]	Wilbarger	(?)				
Do	do	(?)				
Victoria	Victoria	815-956		70-200	Flow.	Three wells.
Waco [4]	McLennan	1,812-1,862	8-4	51-400	Flow.	Numerous wells. Temperature, 103°.
Waco (5 miles west)	do	1,470	4¼	347	Flows.	Pure water. Temperature, 90°.
Waldo (2 miles south)	Coryell	423			−85	Saline water.
Wallisville	Chambers	400		70		
Walters	Travis	700				
Waxahachie	Ellis	990			Flows?	
Do	do	1,700			−15	Soft water.
Waxahachie (6 miles southwest).	do	700			−125	
Weatherford [5]	Parker	500			−50	
Do	do	402		69	−250	Good water.
Do	do	440				
Do	do	488			−250	
Webb	Tarrant	800			−160	Poor water.
West	McLennan	1,690		208	Flows.	
Wexia	Limestone	1,333	4¼			Oil or gas prospect; abandoned; some water at 512 feet.
Whitesboro	Grayson	+800			No flow.	
Whitney	Hill	1,575			+40	
Do	do	1,000		139	Flows.	
Do	do	438			430	
Wichita Falls (1¼ miles south).	Wichita	800				Salt water.

[1] Record, Artesian waters in Texas west of 97th meridian, by R. T. Hill, 52d Congress, 1st session, Senate Ex. Doc. No. 41, part 3, p. 99. Another authority gives 2,700 feet as depth.
[2] Record, 51st Congress, 1st session, Senate Ex Doc. No. 222, p. 270, Washington, 1890.
[3] Analysis, Texas Geol Surv., 4th Ann. Rept., 1892, p 105
[4] Record, 51st Congress, 1st session, Senate Ex. Doc No. 222, pp. 265, 269, Washington, 1890. Analysis, ibid., p. 271.
[5] Record, 51st Congress, 1st session, Senate Ex Doc. No. 222, p. 266, Washington, 1890.

TEXAS—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Wills Point	Van Zandt	1,100	6		To surface.	
Youngsport	Bell	404		1	Flows.	
Do	do	417		½	Flows.	
Youngsport (1½ miles east).	do	433		¼	Flows.	
Youngsport (one-half mile north).	do	444		1	Flows.	
Zimbi [1]	Harris	480				No water; abandoned.
Do	do	520				Do.

PRINCIPAL PUBLICATIONS RELATING TO THE UNDERGROUND WATERS OF TEXAS.

Report of F. E. Roesler, Division Field Agent for Texas, letter from the Secretary of Agriculture transmitting a report on the preliminary investigations to determine the proper location of artesian wells within the area of the 97th meridian and east of the foothills of the Rocky Mountains, 51st Congress, 1st session, Senate Ex. Doc. No. 222, pp. 243–319, Washington, 1890.

Report of E. T. Dumble on the existence of artesian waters west of the 97th meridian, etc., 51st Congress, 1st session, Senate Ex. Doc. No. 222, pp. 99–102, Washington, 1890.

Preliminary reports on the artesian wells of the Gulf Coastal Slope, by J. A. Singley, Texas Geological Survey, 4th Annual Report, 1892, pp. 85–113, Austin, 1893.

On the occurrence of artesian and other underground waters in Texas, etc., west of the 97th meridian, by R. T. Hill, Report on Irrigation, 52d Congress, 1st session, Senate Ex. Doc. No. 41, part 3 (Final Geological Reports), pp. 41–166, plates, Washington, 1893.

Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Tex., with reference to the occurrence of underground waters, by Robert T. Hill and T. Wayland Vaughan, United States Geological Survey, Eighteenth Annual Report, 1896–1897, part 2, pp. 193–321 and plates, Washington, 1898.

Geography and geology of the Black and Grand prairies, Texas, with detailed descriptions of the Cretaceous formations and special reference to artesian waters, by Robert T. Hill, United States Geological Survey, Twenty-first Annual Report, 1899–1900, part 7, pp. 1–649, Washington, 1901.

UTAH.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Bountiful	Davis	400		4–60		
Bountiful (2 miles north of west).	do	580				No water.
Layton	do	500	4½–1¼	Few.		
Paragonah	Iron	412	2			Cool water.
Salt Lake City	Salt Lake	550	8	500		
Do	do	1,105	8	350		
Salt Lake City (12 miles north).		500–750				Several wells.
Smithfield	Cache	410		3		

[1] Record, etc., Texas Geol. Surv., 4th Ann. Rpt., 1892, p. 107.

UTAH—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Spanish Fork	Utah	420	2	60		
Do	do	400	2	5		
Do	do	400	2	70		
Do	do	410	2	40		
Sulphur Springs		650			No flow.	
Vernal	Uinta	975				Abandoned.
Do	do	900	8			Surface water only.

VIRGINIA.

Alexandria (brewery).	Alexandria	430	8	90		
Alexandria (ice works).	do	401	8	20		
Allisonia	Pulaski	400-1,200				Several wells.
Blueridge Springs	Botetourt	500	6	75		
Buckroe Beach		+400				
Claybank	Gloucester	538	1	Several.	Flows.	
Cotman	Henrico	730		40	No flow.	In granite.
Covington	Alleghany	1,138		400		
Crewe	Nottoway	500		Few.	Flow.	
Delton	Pulaski	+400		Not any		Abandoned.
Ditchley		620	1	2	Flows.	
Dublin	Pulaski	475	6	25	−80	
Dymer Creek [1]	Northumberland.	507				
Fairport [2]	do	662	8-6	75	Flows.	
Fort Monroe [3]	Elizabeth City.	907				Drilled in 1864; saline water flowed at 591 feet.
Do. [4]	do	945			Flows.	Saline water.
Foster Falls	Wythe	808		100	−2	
Harrisonburg	Rockingham	420	8		−10	
Gloucester	Gloucester	600		Not any		
Lamberts Point [5]	Norfolk	616		65	+ 7	
Lancaster	Lancaster	+400			No flow.	
Middlebrook	Augusta	460	5	10	−50	
Newport News	Warwick	600		Few.	No flow.	
Norfolk (Money Point).	Norfolk	562		Many.	Flows.	Ferruginous water.
Norfolk (water works). [6]	do	1,760	12-4½	150	Flows.	Saline waters at several horizons.
Northend Point [7]	Elizabeth City.	1,172		Not any		
Oak Springs		400	1	Several.	Flows.	
Pulaski	Pulaski	400-600	6	100	−10	Several wells.
Do	do	1,200				
Reedville	Northumberland.	680	8-6	85	+ 3	Temp. 78°.
Richmond (paper mill).	Henrico	400		Several.		
Richmond (Sherwood Park).	do	900		Not any		
Richmond (Ginter Farm).	do	400		Many.		
Roanoke	Roanoke	1,200	6		− 4	Not in use.
Roanes [8]	Gloucester	716	6	50	+23+	
Stanardsville	Greene	1,150				For oil. No success.
Staunton (asylum)	Augusta	696	5	60	−60	
Staunton (mile east)	do	460	5	9	−30	
Sandy Point [9]	Fairfax	560		Many.	No flow.	Water at 270 feet; rock below.
Stonega	Wise	503	8	55	−16	
Toms Creek			6	100	No flow.	
Williamsburg	James City	876		Not any	do	
Windmill Point	Lancaster	450				Abandoned.

[1] Record, U. S. Geol. Surv., Bull. No. 138, p. 176.
[2] New Jersey Geol. Surv., Report for 1898, pp. 121-122.
[3] Record. Geology of the Virginias, by W. B. Rogers, New York, 1884, pp. 731-736; Am. Inst. Mining Engineers Trans., vol. 24, pp. 380-384; U. S. Geol. Surv., Bull. No. 138, p. 167.
[4] Record, etc., New Jersey Geol. Surv., Report for 1898, pp. 122-126.
[5] Record, U. S. Geol. Surv., Bull. No. 138, p. 172; New Jersey Geol. Surv., Report for 1899, pp. 87-92.
[6] Record, etc., New Jersey Geol. Surv., Report for 1899, pp. 92-102.
[7] Record, Am. Inst. Mining Eng., Trans., vol. 24, pp. 384-386.
[8] New Jersey Geol. Surv., Report for 1899, pp. 86-87.
[9] Record, U. S. Geol. Surv., Bull. No. 138, p. 178.

PRINCIPAL PUBLICATION RELATING TO DEEP WELLS IN VIRGINIA.

Artesian Well Prospects in the Atlantic Coastal Plain Region, by N. H. Darton, United States Geological Survey, Bulletin No. 138, 232 pages, 19 plates, Washington, 1896.

WASHINGTON.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Junction City	Jefferson	800	1½	¼	Flows.	Abandoned.
North Yakima[1]	Yakima	404	6	Many.	Flows.	
Do	do	534-835	8, 6 and 3.	Many.	Flow.	Several wells.
Do	do	650		Many.	Flows.	Temp. 71°.
Do	do	1,050	5-3½		+110	
Do	do	940	6-4		Flows.	
Pasco[2]	Franklin	527 404	6	Many.	Flows.	
Do	do	400		Not any		
Port Blakely	Kitsap	410	4½	500	—6	
Prosser	Yakima	500		Many?	No flow.	
Port Discovery	Jefferson	+800				Abandoned.
Roslyn	Kittitas	700		Many.	Flows.	
Port Discovery (4 miles northeast).		1,230				
Port Townsend	Jefferson	1,060				For coal; unsuccessful.
Port Townsend (3 miles from).	do	1,500				Do.
Port Townsend (9 miles from).	do	1,100				Do.
Port Townsend (15 miles from).	do	700				Do.
Port Townsend (18 miles from).	do	900				Do.

WEST VIRGINIA.

Alva[3]	Tyler	2,700				For oil or gas.
Beaver Creek, (1 mile north).		417				
Big Flint Creek (2 miles southeast from mouth).[4]	Doddridge	2,520				Oil well.
Big Otter	Clay	1,100				Do.
Booher[5]	Tyler	1,859				Several gas wells.
Bridgeport	Harrison	+2,500				Two oil wells.
Brink (near)[6]	Wetzel	2,753				For oil or gas.
Browns Mills (near)[7]	Harrison	1,867				For oil; unproductive.
Buckhannon	Upshur	2,530				For oil.
Buffalo (near)	Putnam	400				
Bulltown	Braxton	1,000				Salt well.
Burning Springs (near).[8]	Wirt	2,010				Oil well.
Burnsville	Braxton	2,750				Small flow of oil.
Cairo[9]	Ritchie	2,060				For oil or gas.
Cairo (1½ miles northwest)[10]	do	1,735				Do.
Cairo (4 miles northeast).[11]	do	2,142				Do.
Cairo (8 miles south).[12]	do	1,652				Small supply of oil.
Cameron (near)[13]	Marshall	3,249				For oil or gas.
Center Point (near).[14]	Doddridge	1,910-2,880				Several oil wells.
Central	do	460	5		—20	Sulphur water.

[1] Records, U. S. Geol. Surv., Bull. No. 108, pp. 56-58, Washington, 1893.
[2] Record, ibid., p. 39.
[3] Record, W. Va. Geol. Surv., Report, vol. 1, p. 336.
[4] Ibid., pp. 332-334.
[5] Ibid., p. 358.
[6] Ibid., p. 345.
[7] Ibid., pp. 249-250.
[8] Ibid., pp. 262-263.
[9] Ibid., p. 302.
[10] Ibid., pp. 303-304.
[11] Ibid., pp. 305-307.
[12] Ibid., pp. 308-309.
[13] Ibid., p. 350.
[14] Ibid., pp. 328-332.

WEST VIRGINIA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Central City	Cabell	2,900	8¼–6¼	Many.	Flows.	Some oil.
Do.[1]	do	2,770				Small flow of gas.
Central City (vicinity).	Boyd	1,675-1,775				Two oil wells.
Charleston (waterworks).[2]	Kanawha	1,840				For oil or gas; unproductive.
Charleston (8 miles above).[3]	do	2,450				Moderate flow of gas.
Charleston (9 miles above).[4]	do	2,542				Small flow of gas.
Charleston (13 miles southwest).[5]	do	2,000				For oil or gas; unproductive.
Cherry Camp (vicinity).[6]	Harrison	2,556-2,839				Several oil and gas wells.
Clarksburg	do	1,700		Many.	Flows.	Some gas.
Clarksburg (5 miles east).	do	2,000				
Clarksburg (4 miles south).	do	750		Many.	Flows.	Salt water.
Clifton	Mason	1,800			—100	
Cross Creek district[7]	Brooke	765				For oil; unproductive.
Dingess Station (near).[8]	Mingo	2,126				For oil or gas.
Eagle Mills (?)(near)[9]	Tyler	2,922				Do.
Ellenboro (3½ miles from).[10]	Ritchie	1,782-1,828				Several oil and gas wells.
Eureka (near)[11]	Pleasants	1,348+ / 1,602				Two oil wells.
Fairfax (northwest of).[12]	Mingo	1,338				For oil or gas.
Fairview (southwest of).[13]	Marion	1,889				Oil well.
Fairview (2 miles northeast).[14]	do	1,997				For oil; unproductive.
Fallsmill	Braxton	1,000				Salt well.
Farmington Station (2 miles east).[15]	Marion	2,811				For oil or gas; abandoned.
Friendly (near)	Tyler					Deep well for oil or gas.
Glenville[16]	Gilmer	2,412	7¼			Oil and gas well.
Do	do	800	2¼			For oil or gas; abandoned.
Grant district[17]	Hancock	1,470				For oil; unproductive.
Do.[18]	Wetzel	3,044				Gas well.
Harpers Ferry	Jefferson	412		Few.	No flow.	
Harrisville	Ritchie	1,600-2,000				Several oil wells.
Harrisville (near)[19]	do	2,500				Oil well.
Hart (near)[20]	Lincoln	3,260				For oil or gas.
Hebron (near)[21]	Pleasants	2,080				Do.
Henry	Preston	703	4¼			
Highland Church (near).[22]	Monongalia Marion line.	3,484	10-5			Oil well.
Holbrook (near)[23]	Ritchie	2,670				Oil well.
Hundred (near)[24]	Wetzel	3,249				Gas well.
Huntington	Cabell	2,975	8¼–6¼			Oil prospect; unsuccessful; much water at bottom.
Do	do	1,200	8–6			
Iuka (near)	Tyler					Several oil wells.
Jarvisville	Harrison	2,500-2,800				Numerous oil wells.

[1] Record, W. Va. Geol. Surv., Report, vol. 1, pp. 275-276.
[2] Record, Pa. 2d Geol. Surv., Reports, Vol. I[5], pp. 331-332.
[3] Ibid., p. 330.
[4] Record, W. Va. Geol. Surv., Report, vol. 1, pp. 271-272.
[5] Record, Pa. 2d Geol. Surv., Reports, Vol. I[5], pp. 332-333.
[6] Records, W. Va. Geol. Surv., Report, vol. 1, pp 252-255.
[7] Record, Pa. 2d Geol. Surv., Reports, Vol. I[5], pp. 327-328
[8] Record, W Va. Geol. Surv., Report, vol 1, pp 278-280
[9] Ibid., pp. 334-335.
[10] Ibid., pp. 311-315.
[11] Ibid., pp. 351-352.
[12] Ibid., pp. 276-277.
[13] Ibid., pp. 239-241.
[14] Ibid., pp. 238-239.
[15] Record, Pa. 2d Geol. Surv., Ann. Report for 1886, part 2, pp. 782-783.
[16] Record, W. Va. Geol. Surv., Report, vol. 1, pp. 259-260.
[17] Record, Pa. 2d Geol. Surv., Reports, Vol I[5], p. 328
[18] Record, W. Va. Geol. Surv., Report, vol. 1, pp. 340-342.
[19] Ibid., p. 319.
[20] Ibid., pp. 280-281.
[21] Ibid., p. 360.
[22] Ibid., pp. 231-232.
[23] Record, W. Va. Geol. Surv., Report, vol. 1, p. 320.
[24] Ibid., p 349.

WEST VIRGINIA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Joetown (1 mile W.)[1]	Marion	3,014				For oil or gas.
Kanawha (and vicinity).[2]	Kanawha	1,000-2,450				Numerous salt and gas wells.
Kenton (?) (vicinity).[3]	Doddridge	2,115				For oil or gas.
Letart (near)[4]	Mason	2,139				Do.
Liberty Township[5]	Marshall	2,934				For oil or gas, unproductive.
Long Run Station (near).[6]	Doddridge	2,701				For oil or gas.
Lot (near)[7]	Wetzel	2,588				Do.
Loudensville (5 miles north).[8]	Marshall	1,935				Do.
Lightburn (vicinity)	Lewis	2,700				For oil or gas; abandoned.
Little Mills (near)[9]	Tyler	2,690				For oil or gas.
Macksburg (near)[10]	Noble	1,695				Do.
Malden[11]	Kanawha	1,800				Gas well.
Mannington (near)[12]	Marion	1,928				For oil or gas.
Mannington (1 mile above).[13]	do	3,144				Do.
Mannington (3 miles southwest).[14]	do	3,042				Do.
Mannington (3 miles north).[15]	do	2,895				Oil well
Mannington (6 miles northwest).[16]	do	3,010				Do.
McKim (near)[17]	Tyler	1,942				For oil or gas.
Martinsburg	Berkeley	485				Abandoned.
Do	do	450				
Metz (near)[18]	Marion	2,992				For oil or gas.
Middlebourne (few miles below).[19]	Tyler	1,562				Small supply of oil.
Middlebourne (4 miles north).[20]	do	1,638				Oil well.
Miletus (near)[21]	Doddridge	2,930				For oil or gas.
Do	do	2,670				Gas well.
Morgantown[22]	Monongalia	2,267				For oil or gas.
Moundsville (near)[23]	Marshall	1,470				Do.
Moundsville (vicinity).	do	1,400-1,413				Several oil wells.
Moundsville (3 miles northeast).[24]	do	578				Numerous oil wells.
Murphytown (vicinity).[25]	Wood	2,177				For oil or gas.
Newburg	Preston	3,009				For gas; unsuccessful.
Do	do	865			—18	
New Cumberland	Hancock	+600				Gas well.
New Cumberland (2 miles east).[26]	do	1,198				Oil well.
Oxford[27]	Ritchie	2,106				Do.
Oxford (7 miles above)[28]	Doddridge	2,484				Do.
Parkersburg (near)[29]	Wood	2,035				For oil or gas.
Parkersburg (5 miles northeast).[30]	do	3,016				Do.
Peoria	Harrison	2,300				Do.

[1] Record, W. Va. Geol. Surv., Report, vol. 1, pp. 345-347.
[2] Records, Pa. 2d Geol. Surv., Reports, Vol. I[5], pp. 329-333; W. Va. Board of Centennial Managers, Resources, Report by Maury and Fontaine, pp. 287-290.
[3] Record, W. Va. Geol. Surv., Report, vol. 1, p. 335.
[4] Ibid., pp. 281-282.
[5] Record, Pa. 2d Geol. Surv., Report, Vol. I[5], pp. 328-329.
[6] Record, W. Va. Geol. Surv., Report, vol. 1, pp. 325-326.
[7] Ibid., p. 339.
[8] Ibid., 351-352.
[9] Ibid., p. 355.
[10] Ibid., pp. 298-299.
[11] Record, Pa. 2d Geol. Surv., Reports, Vol. I[5], p. 331.
[12] Record, W. Va. Geol. Surv., Report, vol. 1, pp. 241-242.
[13] Ibid., pp. 242-243.
[14] Ibid., pp. 243-244.
[15] Ibid., pp. 244-246.
[16] Ibid., pp. 246-247.
[17] Ibid., p. 359.
[18] Record, W. Va. Geol. Surv., Report, vol. 1, p. 348.
[19] Ibid., p. 361.
[20] Ibid., p. 360.
[21] Ibid., pp. 323-324.
[22] Record, Pa. 2d Geol. Surv., Reports, Vol. I[5], p. 329.
[23] Record, W. Va. Geol. Surv., Report, vol. 1, pp. 362-363.
[24] Ibid., p. 364.
[25] Ibid., pp. 292-294.
[26] Ibid., p. 369.
[27] Ibid., pp. 321-322.
[28] Ibid., pp. 322-323.
[29] Ibid., p. 285.
[30] Ibid., pp. 296-298.

WEST VIRGINIA—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Petroleum Station (1½ miles north).[1]	Ritchie	1,800				Oil well.
Piney Fork[2]	Wetzel	2,640				For oil or gas.
Poe District[3]	Hancock	1,700				For oil; unproductive
Point Pleasant (6 miles below).[4]	Mason	2,942				For oil or gas.
Ravenswood (near)[5]	Jackson	2,232				Do.
Ritchie Court-House.[6]	Ritchie	1,724-1,918				Several oil and gas wells.
Ronceverte	Greenbrier	800				For oil; abandoned.
Salem	Harrison	2,100-2,800				Oil wells.
Sardis (vicinity)[7]	do	3,081				For oil; abandoned.
Sedalia (near)[8]	Doddridge	2,800				Large gas well.
Shanghai	Berkeley	714	7	Few.		Sulphur water at 188 feet; abandoned.
Sisterville (near)	Tyler					Large oil well.
Sistersville (2½ miles southwest).[9]	do	1,865				For oil or gas.
Smithfield (near)[10]	Wetzel	3,282				Oil well.
Smithfield (2 miles northeast).[11]	do	3,106				Do.
Spencer (asylum farm).[12]	Roane	2,750				For oil or gas.
Spencer (about 10 miles southwest).[13]	do	1,623-2,302				Several oil and gas wells.
Sutton (1½ miles below).[14]	Braxton	2,725				Oil well.
Ten Mile District[15]	Harrison	2,750				For oil or gas; unproductive.
Vadis (near)[16]	Lewis	2,703				Oil well.
Do.[17]	Doddridge	2,207				For oil; unsuccessful on account of water.
Wadestown (near)[18]	Monongalia	3,090				Oil well.
Do.[19]	do	3,112				Do.
Do.[20]	do	3,300	6½			Gas well.
Waverly (6 miles south).[21]	Wood	2,261-2,208				Two oil wells.
Wellsburg[22]	Brooke	1,217				Numerous deep gas wells; now run out.
Do.[23]	do	1,310				Gas well.
Weston	Lewis	2,700				For oil; unsuccessful
Do	do	1,450				Small flow of oil.
Weston (2 miles below).	do	2,165?				Gas well.
Weston (10 miles southeast).[24]	do	2,401				Oil well.
Wick (near)[25]	Tyler	1,915				For oil or gas.
Williamstown (1½ miles below).[26]	Wood	1,504-1,673				Do.
Williamstown (4 miles below).[27]	do	710-1,138				Two oil wells.
Winfield (?)	Putnam	500				Two wells.
Wheeling[28]	Ohio	2,095				For oil or gas.
Wheeling (near).[29]	do	4,500	4½			Do.
Wheeling (3 miles east-northeast).[30]	do	2,000				For oil or gas; unsuccessful.
Wordley (near)[31]	Monongalia	2,830-2,960				Gas well.

[1] Record, W. Va. Geol. Surv., Report, p. 301.
[2] Ibid., p. 337.
[3] Record, Pa. 2d Geol. Surv., Reports, Vol. I[5], p. 327.
[4] Record, W. Va. Geol. Surv., Reports, vol. 1, pp. 273-274.
[5] Ibid., pp. 283-284.
[6] Ibid., pp. 317-318.
[7] Ibid., pp. 248-249.
[8] Ibid., pp. 326-327.
[9] Record, W. Va. Geol. Surv., Report, vol. 1, p. 357.
[10] Ibid., p. 343.
[11] Ibid., pp. 343-344.
[12] Ibid., pp. 264-266.
[13] Ibid., pp. 267-269.
[14] Ibid., 269-270.
[15] Ibid., p. 251.
[16] Ibid., pp. 257-258.
[17] Ibid., pp. 258-259.
[18] Ibid., pp. 233-234.
[19] Ibid., pp. 232-233.
[20] Ibid., pp. 230-231.
[21] Ibid., pp. 292-294.
[22] Record, Ohio Geol. Surv., Report, 1888, Vol. VI, pp. 337-339.
[23] Record, Pa. 2d Geol Surv., Ann. Report for 1886, part 2, pp. 783-784; W. Va. Geol. Surv., Report, vol. 1, p. 367.
[24] Record, W. Va. Geol. Surv., Report, vol. 1, pp 255-256.
[25] Ibid., p. 359.
[26] Ibid., pp. 290-291.
[27] Ibid., p. 289.
[28] Ibid., p. 366.
[29] Ibid., pp. 364-365.
[30] Record, Pa. 2d Geol. Surv., Ann. Report, 1886, part 2, pp. 781-782.
[31] Record, W. Va. Geol. Surv., Report, vol. 1, pp. 234-237.

PRINCIPAL PUBLICATIONS RELATING TO DEEP BORINGS IN WEST VIRGINIA.

West Virginia Geological Survey, Reports, vol. 1, by I. C. White, 392 pages, Morgantown, 1899.

Seventh Report on the Oil and Gas Fields of Western Pennsylvania for 1887–1888. Pennsylvania Second Geological Survey, Vol. I[5], by J. F. Carll, 356 pages, Harrisburg, 1890.

WISCONSIN.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Berlin	Green Lake	425	6	40	+3	Temp. 52°.
Do	do	450		40	+3	
Bristol	Kenosha	815	5		−32	
Brodhead	Green	1,000	4–8	Each 150	+12	Two wells. Water from 250–300 feet mainly. Granite, 700–1,000 feet. Temp. 52°.
Burlington	Racine	1,000	9	Many.	Flows.	
Do	do	800	9	Many.	−8	
Cassville	Grant	1,100	6	Many.	Flows.	
Clinton	Rock	650		Many.	−30	
Dale	Outagamie	490		Many.	−15	
De Soto	Vernon	466	6	126	+26	Temp. 52°.
Durand	Pepin	550	6	180	+35	Good water.
Durand (5 miles southeast).	do	402	10–6	2	−282	Do.
East Troy	Walworth	2,200			No flow.	
Elkhorn	do	1,050	8–6	Many.	−155	
Elroy	Juneau	500 or 600			No flow.	Not in use.
Fond du Lac	Fond du Lac	750	10	Many.	−10	Two wells.
Do	do	600	10	Many.	−10	Do.
Do	do	480	10	Many.	−10	
Do.[1]	do	425				
Genoa	Vernon	460	6	200	−30	
Greenbay	Brown	950		70	+14	Temp. 53°. Several wells.
Hartford	Washington	920		40		To be deepened.
Haven	Sheboygan	600			−40	
Do	do	420			−11	
Hudson	St. Croix	400–500				
Independence	Trempealeau	438			−12	Well in bad order; abandoned.
Jamesville[2]	Rock	1,100–1,033	8	500	+35	Two wells and magnesia; water to +48 at 683 feet.
Jamesville (fair ground).	do	±1,100		Not any	No flow.	Abandoned.
Kilbourn	Columbia	1,320				
La Crosse[3]	La Crosse	573	6	100	−16	Some lime and iron; city supply.
Madison	Dane	736–821	10	Many.	+54	Several wells. Temp. 51°.
Marinette	Marinette	716	4	Many.	+21	Water at 405 and 415 feet only; granite at 716 feet. Temp. 49°.
Menomonee Falls	do	1,700	8	Many.	Nearly to top.	
Millville	Grant	487	7	Several	−369	
Milwaukee[4]	Milwaukee	1,048	4	Many.	+60	
Milwaukee (near)[5]	do	1,200		300	+50	
Monroe	Green	+400				
Oconto	Oconto	±400		450	+24	Temp. 50°.
Oil City[6]	Monroe	510		Many.	+25	Main body of water at 300 feet.
Onalaska	La Crosse	450		284	To surface.	
Oshkosh[7]	Winnebago	961	6	Many.	−4	Granite below 700 feet.

[1] Record, Wis. Geol. Surv., Reports, 1873–1877, vol. 2, p. 153.
[2] Ibid., pp. 166–197.
[3] Record, Wis. Geol. Surv., Reports, 1873–1879, vol. 4, pp. 60–61.
[4] Record, Wis. Geol. Surv., Reports, 1873–1877, vol. 2, p. 164.
[5] Analysis, ibid., p. 164.
[6] Record, Wis. Geol. Surv., Reports, 1873–1879, vol. 4, pp. 59–60.
[7] Record, Wis. Geol. Surv., Reports, 1873–1877, vol. 2, p. 156.

WISCONSIN—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Oshkosh[1]	Winnebago	695	6	Many.	−1	Granite below 665 feet.
Do	do	537	5	Many.	−1	
Oshkosh (normal school).	do	613	5	Many.	−4	
Oshkosh	do	505	5	Many.	−1	Several other similar wells.
Palmyra[2]	Jefferson	750			−14	Water at 263 feet; oil at 257 feet.
Patch Grove	Grant	487	9-6	Several	−440	Good water; two o her similar wells in vicinity.
Platteville	do	1,000				
Prairie du Chien[3]	Crawford	960	8-5¼	600	+60	Temp. 56°. Water slightly salty; brine at 514 feet; several wells.
Racine[4]	Racine	1,240		Many.	+65	Several wells.
Do	do	1,350	4	Many.	+92	
Richland Center	do	750	6	2,400	−11	
Riverfalls	Pierce	500	8-6	200	−6	No water below 400 feet.
Do	do	400	8-6	200	−6	
Rock Elm	do	520	8		−120	Abandoned.
Sheboygan[5]	Sheboygan	1,475	4	225	+104	Temp. 59°. Flow at 1,340 feet.
Sherwood	Calumet	1,035				
Superior	Douglas	927	6			Water brackish.
Tornado	Door	1,040	8-6	Many.	−122	
Tomar[6]	Monroe	492			No flow.	
Two Rivers	Manitowoc	1,700	8	Many.	No flow.	Abandoned; granite in bottom.
Urne	Buffalo	471	6			
Watertown	Jefferson	1,145	9	600	+11	Temp. 47°.
Waukesha	Waukesha	1,000-1,500			−35	Several wells.
Westbend	Washington	1,500		Many.	−4	
West Depere	Brown	810	5	250	+26	Temp. 65°
Western Union Junction.[7]	Racine	1,263		Few.	+40	
Whitewater	Walworth	950		200	+20	

PUBLICATIONS RELATING TO DEEP BORINGS IN WISCONSIN.

Wisconsin Geological Survey, Reports, 1873-1877, vol. 2, part 2, pp. 97-405.
Wisconsin Geological Survey, Reports, 1873-1879, vol. 4, part 1, 98 pages.

WYOMING.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Aladdin	Crook	±1,000				No water.
Almond	Sweetwater	1,000				Strong sulphur water.
Cambria[8]	Weston	1,300				In progress.
Cheyenne	Laramie	1,145				
Clifton (north of)[9]	Weston	1,002		Few.	Flows.	Mineral water.
Dallas	Fremont	800-1,200			Flow.	Oil wells.
Douglas	Converse	500			+20	Some oil; much water.
Gillette	Crook	865			−485	
Hilliard	Uinta	484				For oil; unsuccessful

[1] Ibid., p. 156.
[2] Ibid., pp. 161-162.
[3] Record, Wis. Geol. Surv., Reports, 1873-1879, vol. 4, pp. 61-62.
[4] Record, Wis. Geol. Surv., Rpts., 1873-1877, vol. 2, p. 163.
[5] Record and analysis, Ibid., p. 164.
[6] Record, Wis. Geol. Surv., Rpts., 1873-1879, vol. 4, p. 60.
[7] Record, Wis. Geol. Surv., Rpts., 1873-1877, vol. 2, pp. 162-163.
[8] Record, U. S. Geol. Survey, 21st Ann. Rept., 1889-1900, part 4, p. 572.
[9] Ibid., p. 571.

WYOMING—Continued.

Location.	County.	Depth.	Diameter.	Yield per minute.	Height of water.	Remarks.
		Feet.	*Inches.*	*Gallons.*	*Feet.*	
Jerome[1]		520				
Judson	Albany	540		Few.	Flows.	Sulphur water.
Laramie	do	1,015		30	Flows.	Good water.
Do	do	1,470				
Leach	do	510	5		No flow.	
Moorcroft (8 miles northwest).	Crook	1,300				For oil; unsuccessful.
Moorcroft (10 miles northwest).	do	800				Two small oil wells.
Mullen	Fremont	1,200		Several.		Oil and sulphur water.
Newcastle	Weston	1,950		Several.	Flows.	For oil; unsuccessful.
Do	do	1,340				Some oil at about 400 feet.
Do	do	420				Some oil.
Newcastle (3½ miles southwest).	do	720				No product.
Oil City[2]	Natrona	1,130				Oil and gas.
Oxford Ranch	Albany	540		Few.	Flows.	For oil; unsuccessful.
Rawlins	Carbon	450	4½	200		Several wells.
Do	do	487		400	Flowed originally.	
Do	do	928		350	Flowed originally.	Water from 466 feet.
Salt Creek oil field[3]	Natrona	809–1,200				Oil wells.
Sheridan	Sheridan	500	2½	½		
Sussex	Johnson	1,300		Few.		Water at 358 and 1,120 feet.

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Petroleum of the Shoshone Anticlinal, by W. C. Knight, University of Wyoming, petroleum series, Bulletin No. 2, 34 pages, January, 1897.

Oil Fields of Crook and Uinta Counties, Wyoming, by W. C. Knight, University of Wyoming, Petroleum series, Bulletin No. 3, 31 pages, November, 1899.

A Preliminary Report on the Artesian Basins of Wyoming, by W. C. Knight, University of Wyoming, Wyoming Experiment Station, Bulletin No. 45, 251 pages, plates, map, June, 1900.

Preliminary Description of the Geology and Resources of the Southern Half of the Black Hills and Adjoining Regions in South Dakota and Wyoming, by N. H. Darton, United States Geological Survey, Twenty-first Annual Report, 1899–1900, pp. 489–599, plates, maps, Washington, 1901.

[1] Analysis, ibid., p. 571.
[2] Record, etc., Wyo., Ann. Rept. Geologist, Jan., 1888, p. 32.
[3] Record, Wyoming University, Bull. No. 1 (Petroleum series), 1896, pp. 18–19.

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DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 62

WASHINGTON
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1902

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

HYDROGRAPHY

OF THE

SOUTHERN APPALACHIAN MOUNTAIN REGION

PART I

By HENRY ALBERT PRESSEY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1902

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., December 18, 1901.

SIR: I have the honor to transmit herewith a manuscript prepared by Mr. H. A. Pressey, one of the hydrographers of this Survey, relating to the Southern Appalachian mountain region. This is the outcome of systematic measurements of the water supply from this area and of special investigations made in connection with a general inquiry as to the importance of the streams in the development of the country.

There has been a widespread movement for the acquisition by the Government of the forested lands within the Southern Appalachians and the setting aside of these as a reserve similar in character to the great forest reservations existing in the West. In this popular movement Prof. J. A. Holmes, State geologist of North Carolina, has been especially active. He has been cooperating with this Survey in all matters pertaining to the investigations in North Carolina, and has been the representative of the State in arranging for the disbursement of funds made available by the State for extending the systematic work carried on in that region. At his suggestion and with his active assistance the surveys and examinations described by Mr. Pressey have been made.

The importance of a full knowledge of this region is apparent when we consider the size and number of the streams issuing from this central mountain area. Water-power development, especially in the manufacture of cotton, is proceeding rapidly, and there is no portion of the country for which definite official data upon the water resources are more frequently required than for this area. I recommend, therefore, that the material prepared by Mr. Pressey be published in the series of Water-Supply and Irrigation Papers, as Nos. 62 and 63 of that series.

Yours respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

Austell
Mableton
Smyrna
Vinings
Chamblee
Doraville
Tucker
Stone Mtn.
Lithonia
Decatur
Clarkston
Scottdale

HYDROGRAPHY OF THE SOUTHERN APPALACHIAN MOUNTAIN REGION.

PART I.

By HENRY A. PRESSEY.

INTRODUCTION.

The region herein described occupies portions of the States of Virginia, North Carolina, South Carolina, Tennessee, Georgia, and Alabama. It is elevated far above the surrounding country and stands out as a physiographic unit. Its rivers, topography, and resources are described in as much detail as the time available for field investigation permitted.

Special thanks are due to Mr. E. W. Myers, resident hydrographer for North Carolina and South Carolina, for his investigations and very complete reports on several of the drainage areas, the principal facts from which are embodied herein. Messrs. Cleveland Abbe, jr., L. V. Branch, N. C. Curtis, and Ernest Graves were also engaged upon the reconnaissance, and the success achieved was largely due to their assistance. The measurements of the streams to the south and west of the French Broad were under the charge of Prof. B. M. Hall, resident hydrographer for Georgia and Alabama, who was assisted by Max Hall, W. E. Hall, J. R. Hall, J. C. Conn, and H. G. Stokes. The photographs used for illustrations were taken by various members of the United States Geological Survey and of the United States Bureau of Forestry. Pls. IX and XI are from photographs by R. H. Scadin, Pls. XXXIX and XLII are by courtesy of Prof. J. A. Holmes.

GENERAL FEATURES OF REGION.

MOUNTAINS.

PHYSIOGRAPHY.

The great Appalachian mountain system stretches from Maine, in a general southwesterly direction for nearly 1,300 miles, through the States of Vermont, New York, Pennsylvania, Maryland, Virginia, North Carolina, South Carolina, and Tennessee, terminating in northern Alabama. In New York the range consists of high hills, the mountains gradually rising in elevation in Pennsylvania, where an

average height of 2,000 feet above the sea, or 1,000 to 1,500 feet above the adjacent Cumberland Valley, is reached. At Potomac River, in the vicinity of Harpers Ferry, the elevation of the peaks is again reduced to about 800 feet. From the Potomac south the ranges are much higher and broader, spreading out into the great Blue Ridge, the Shenandoah, the Allegheny, and the Greenbriar mountains, ranges with broad, fertile valleys between, of which the Valley of Virginia, or Shenandoah Valley, has a national reputation for scenic beauty and fertility. Forty-five miles below the Potomac is Mount Marshall, 3,150 feet high, and a little farther south, near Luray, are Stoneyman and Hawks Bill, 4,031 and 4,063 feet high, respectively. These are the highest summits of the Blue Ridge north of North Carolina. The ranges extend in nearly parallel lines through the States of Virginia and West Virginia, and enter North Carolina and Tennessee near their common boundary, culminating in the Iron and the Great Smoky ranges, which with numerous cross chains form the great mountain region of the Southeastern States. In this mountain mass 288 peaks exceed a height of 5,000 feet, and 27 peaks have an elevation greater than Mount Washington (6,293 feet). From North Carolina and Tennessee the ranges extend more to the westward through Georgia and into Alabama, with outlying ranges in South Carolina, and are finally lost in hills forming the headwaters of the Gulf drainage. The general features of the southern and most massive portion of the Appalachians, with the drainage, are shown in Pl. I.

This great mountain system forms the backbone and watershed of the eastern part of the United States. The greatest masses and the highest peaks are in western North Carolina and eastern Tennessee, which region may be considered a high plateau, of which the Smoky Mountains form the western boundary of the highest portion and the Blue Ridge the eastern boundary. The latter ridge extends across the State of North Carolina in a general northeast-southwest direction until it reaches the southern border of the State, when it turns to the west and for a long distance (about 40 miles) forms a part of the boundary between North Carolina and South Carolina, passing at length into the State of Georgia and meeting again the Great Smoky Range. The area of the region included between these two ranges, which approaches to almost a point at its northern and southern extremes and at its widest portion has a width of 55 miles, is approximately 6,000 square miles.

The most striking characteristic of the Blue Ridge is the great difference in slope of its opposite sides. The rivers flowing to the west into the Tennessee and the Ohio head in the gaps upon the divide and for miles flow in broad, smoothly rounded, drift-filled valleys before entering the narrow, rock-cut gorges of their lower courses, while the rivers flowing to the east plunge downward in a series of cascades, falling several thousand feet in a distance of a few miles. The latter

streams can hardly be said to have valleys, but simply V-shaped gorges, through which they tumble and foam until they reach the Piedmont Plain, which extends along the southeastern base of the Appalachian system. The surface of this plain has a general eastward slope from an altitude of about 1,000 feet at its western edge to 250 or 300 feet on the east, where it merges into the Coastal Plain.

The Smoky Mountains, on the western edge of the high plateau referred to, are extended to the north in the Bald and the Iron mountains and to the south in the Unaka Range. These mountains are much more massive and reach far greater elevations than the summits of the Blue-Ridge. Many of their peaks attain heights of more than 6,000 feet. Unlike the Blue Ridge, their slopes are equally steep on both sides, their outlines are angular and rugged, and descents of 4,000 feet from the crest to the stream bed are not uncommon.

Several cross chains connect the Smoky and Blue Ridge ranges, cutting the plateau into a number of small basins, each nearly surrounded by mountains and having its own independent system of rivers and drainage, so that nowhere in this region do we find extended fertile valleys, as in Virginia and Tennessee, but instead in every direction high mountain ranges cut off the view and give it the appearance of a rocky and truly mountainous country.

The highest and most massive of the cross chains is the Black Mountains—named for their somber vegetation of balsam and other evergreens—which really consist of two chains having a united length of 40 miles and extending in a northwesterly direction from the Blue Ridge through the counties of Buncombe and Yancey and forming a connecting link between the Blue Ridge and the Smoky mountains. This range of mountains comprises 25 peaks, 18 of which are more than 6,000 feet in height. On their western slopes rise the eastern tributaries of the French Broad, the valley of which separates the Black Mountains from the Pisgah and the Newfound mountains, other of the cross chains, on the western slopes of which rise the eastern tributaries of Pigeon River. The western tributaries of the Pigeon flow from the Balsam Mountains, a range having an average elevation of 5,600 feet and comprising 23 summits with elevations exceeding 6,000 feet. This range extends from the South Carolina line to the Smoky Mountains. Still farther to the west are the Cowee Mountains, with a mean height of 4,800 feet. Rising at the southern end is Yellow Mountain, with an elevation of 5,133 feet. The last of the cross ranges to the west is the massive double chain of the Nantahala and the Valley River mountains, with a mean height of 5,000 feet. East of the Black Mountains are the Linville Mountains, through which Linville River has cut its stupendous chasm.

The Smoky and the Blue Ridge mountains, with their numerous cross chains, form the culmination of the Appalachian mountain sys-

tem, and are the highest and most massive mountains in the Unite States east of the Rockies. Following is a list of the peaks whic exceed in elevation 6,000 feet:

Highest peaks in Southern Appalachians.

	Feet.
Smoky Mountains:	
Mount Buckley	6,599
Clingmans Dome	6,660
Mount Love	6,443
Mount Collins	6,188
Mount Alexander	6,447
Mount Henry	6,373
Mount Guyot	6,636
Tricorne Knob	6,188
Ravens Knob	6,230
Thermometer Knob	6,157
Luftee Knob	6,232
Cataloochee Mountain	6,159
Roan High Knob	6,313
Roan High Bluff	6,287
Grassy Ridge (bald)	6,226
Mount Curtis	6,568
Mount Leconte	6,612
Master Knob	6,013
Oconee Mountain	6,135
Peck Peak	6,232
Mount Safford	6,535
Balsam Mountains:	
Enos Plotts Balsam	6,090
Jones Balsam	6,224
Rockstand Knob	6,002
Brother Plott	6,246
Amos Plotts Balsam	6,278
Rocky Face	6,031
Double Spring Mountain	6,380
Richland Balsam	6,540
Chimney Peak	6,234
Spruce Ridge Top	6,076
Reinhardt Mountain	6,106
Devils Court-house	6,049
Sams Knob	6,130
Cold Mountain	6,000
Mount Hardy	6,102
Jones Knob	6,209
Mount Junaleska	6,223
Rocky Trail	6,488
Water Rock Knob	6,399
Black Mountain	6,275
Shining Rock	6,040
Rough Butt Bald	6,010
Cold Springs Knob	6,010

Troy
Carthage
Rockingham
Wadesburg
Chesterfield
Darlington
Monroe
Sandy R.
Big Lick
Big Bear
Big Muddy
Big Muddy
Big Muddy

	Feet.
Black Mountains:	
Blackstocks Knob (northwest chain)	6,386
Potato Top (northwest chain)	6,487
Black Dome (main chain)	6,502
Mount Gibbs (main chain)	6,608
Mount Hallback or Sugarloaf (main chain)	6,432
Mount Mitchell (main chain)	6,711
Balsam Cone (main chain)	6,697
Black Brother (main chain)	6,645
Cattail Peak (main chain)	6,609
Hairy Bear (main chain)	6,622
Deer Mountain (main chain)	6,220
Bowlems Pyramid or Celo (main chain)	6,351
Locust Mountain	6,088
Burnt or Long Mountain	6,238
Clingman Peak	6,611
Yeates Knob or Big Butt	6,001
Potato Knob	6,419
Patton Knob	6,079
Craggy Range:	
Big Craggy	6,106
Bull Head	6,072

The foregoing table shows a total of 64 peaks having elevations of 6,000 feet or higher. There are 288 peaks that exceed in height 5,000 feet, and the number that exceed 4,000 feet is much greater.

GEOLOGY.

For the following brief description of the geology of the region the writer is indebted to Mr. Arthur Keith, of the United States Geological Survey, who has made a careful study of the Southern Appalachians:

"The geologic formations which underlie this mountain district may be divided into four large groups. Each differs widely from the others in age, and has very distinct features of its own. These broad differences have expressed themselves in such major topographic features as the Appalachian Valley, the Appalachian Mountains, and the Piedmont Plateau. These differences are also largely responsible for the principal variations in the character of the surface in the mountain district itself.

"The Appalachian Valley is underlain by a series of limestones, shales, and sandstones, mainly of Silurian and late Cambrian age, forming the youngest of the four groups in this region. Small outliers of these formations are included within the area of the mountains near the border of the Appalachian Valley.

"The second group occupies the northwestern border of the mountain district, chiefly northeast of French Broad River. It consists of a series of quartzites, conglomerates, and shales of Lower Cambrian age. A second large area of these rocks occupies the Blue Ridge and adjacent territory nearly in the center of this district.

"The third group is of Cambrian age. It occupies the northwest border of the mountain mass, corresponding in position to the previous group but developed southwest of French Broad River in the Smoky and the Unaka mountains. The group consists of conglomerates, graywackes, sandstones, schists, and slates, and is called the Ocoee group. This and the preceding two groups were composed of the waste from older rocks, which was deposited under water. The thickness of the strata is approximately the same in the Ocoee group and the formations of the Appalachian Valley. The Lower Cambrian quartzites and shales of the second group have only from one-fourth to one-third of the thickness of either of the preceding groups.

"The fourth group is much the largest of all, both in actual bulk and in area. It consists in the main of formations of the Archean, or oldest known age. The different rocks include several kinds of granite, diorite, mica- and hornblende-gneiss, and various schists. A large number of these were of igneous origin, but the original nature of many of the gneisses and schists is unknown. Formations also included in this group are the ancient volcanic rocks. These are developed most prominently in connection with the Cambrian quartzites in the northeastern part of the mountain district.

"Much of the surface of the Appalachian Mountains is exceedingly ancient. During the later geologic periods it has been subjected to the various natural agencies of destruction, and has been worn down according as the rocks presented at the surface were susceptible to these influences. The materials composing these formations are attacked in varying degrees by solution and by chemical processes connected with atmospheric and underground water. Certain minerals—for instance, carbonate of lime—are readily dissolved by natural waters, and the rock in wasting away leaves behind only the less soluble portions in the form of clay. To this capability is directly due the reduction of the great valley below the level of the mountain mass. Other minerals—for instance, feldspar—are in part dissolved and in part chemically altered and decomposed by natural waters, so that the coherence of the rock which contains them is largely destroyed. Two groups in this region have a large proportion of feldspar in their make-up, and their surfaces have been gradually lowered by its breaking down. These are the Ocoee group and the Archean group. A third mineral, quartz, is comparatively little changed by solution or chemical action near the surface. Formations made up in large part of this mineral retain their altitudes most persistently, and are usually the last to be reduced. This composition is most pronounced in the Lower Cambrian group, but is shared also by the Ocoee group and the Archean group. Although the thickness of the Lower Cambrian quartzites is so much less than that of the other groups, their resistance to solution has caused them to remain upheld in very high ridges and peaks. To this are due the cliffs of the Chilhowee, Camp

ESCARPMENT OF THE BLUE RIDGE AT BLOWING ROCK, N. C.

Creek, and Iron mountains, and the rugged crags of Grandfather. In the case of the Ocoee and Archean groups their immense thickness and the amount of quartz which they contain have maintained the greatest elevations presented in this region. Of this the mighty domes of the Smokies, the Balsams, and the Roan, and the lofty peaks of the Blacks are witnesses."

RIVERS.

The region is well watered. From it several of the largest rivers of the country receive their supply. The main divide of the river systems is the Blue Ridge. This chain, which enters the State of North Carolina in Alleghany County, extends southwest between Wilkes and Ashe counties and through Watauga County. At Grandfather Mountain, which is at the junction of Watauga, Mitchell, and Caldwell counties, the chain turns more to the south, following the boundaries between Mitchell and Caldwell counties and between McDowell, Yancey, and Buncombe counties, reaching the State line in Macon County. In this ridge and its spurs, cross ridges, and foothills many of the rivers of the Southeastern States have their origin. A view of an escarpment of the Blue Ridge at Blowing Rock, N. C., near Grandfather Mountain, is shown in Pl. III. The States of Virginia, North Carolina, South Carolina, Georgia, Alabama, Tennessee, and West Virginia are partially watered by rivers rising in mountains near the North Carolina and Tennessee State line. One of the principal upper tributaries of the Ohio (the Kanawha) and one of the largest feeders of the Mississippi (the Tennessee) head in the same mountains, and the region may justly be termed one of the chief watersheds of the United States. The drainage basins of the largest rivers are shown in Pl. II.

Flowing into the Atlantic are the Yadkin, Catawba, Broad, Saluda, and Chatooga; into the Gulf are the Chattahoochee and the Coosa. New River flows to the north and enters the Great Kanawha, whose waters finally reach the Mississippi through the Ohio River. Into the Mississippi flow the waters of the Tennessee and its large tributaries—the Holston, the Nolichucky, and the French Broad. From the western slopes of the Blue Ridge flow the headwaters of the great Tennessee river system. This drainage basin has an area of about 1,500 square miles and a length of 300 miles in North Carolina, and a fall of about 1,000 feet between its source and the North Carolina and Tennessee State line. The Cheoah, the Nantahala, the Oconalufty, and the Tuckasegee, all large streams with a width of from 50 to 100 yards, join their waters to the Tennessee, and after receiving them the latter river flows through the Great Smoky Mountains in a narrow and rocky gorge. The Hiwassee joins it in Tennessee.

All of the large streams that flow to the west have the same general

characteristics, i. e., heavy, precipitous falls in the first portion of their courses, then long even flows, with but little fall, across the broad plateaus, finally cutting through the mountain ranges on the border line of North Carolina and Tennessee, where they have rapid and precipitous falls, in some cases more than 1,000 feet in a few miles.

After leaving the State of North Carolina the Tennessee flows in a northwesterly direction for about 300 miles, through the State of Tennessee, being joined by the Holston and the Nolichucky, tributaries which carry as much water as the parent stream. The Holston receives its southern branches from this same mountain region. The Watauga, one of the chief tributaries of the Holston, rises in the center of the mountain district around Grandfather Mountain, and flows in a northwesterly direction through Watauga County, with the high, steep slopes of the mountain sides on either hand, and with frequent falls of a few feet over its rocky bed. After flowing through the Iron Mountains in a rocky gorge and entering Tennessee the Watauga is joined by Roan and Elk creeks, which have drainage areas with the same characteristics as its own. After the junction of these three streams the river flows through Carter and Washington counties, receiving tributaries on either side, the chief of which are Doe River, Buffalo Creek, and Stony Creek. About 20 miles southwest of Bristol the Watauga joins the South Fork of the Holston, and farther down, near Kingsport, the two forks of the Holston unite, forming one of the chief rivers of the State of Tennessee. Near Knoxville the Holston is joined by Nolichucky River, a stream but little smaller than itself, which derives its headwaters a few miles south of the source of the Watauga.

The Nolichucky is formed by the junction of the North Toe, the South Toe, and Caney River, all of which rise in the high mountains of Mitchell and Yancey counties, on the western border of North Carolina. The headwaters of the North Toe are separated from those of Elk Creek, of the Watauga drainage, by a narrow ridge. The North Toe flows to the southwest until its junction with the South Toe, which rises in the Black Mountains, after which it flows in a westerly direction and is joined by Caney River, which also rises in the Black Mountains but flows through a comparatively flat and open valley, draining a large part of Yancey County. After the junction with Caney River the stream is known as the Nolichucky, and flows to the west for 200 miles through the State of Tennessee, receiving numerous tributaries, the chief of which are Lick Creek and French Broad and Pigeon rivers.

The French Broad rises in the Blue Ridge, at the State line between North Carolina and South Carolina, flows in a northwesterly direction, at first with considerable fall, then enters the broad plateau, and with sluggish, even flow continues its course westward until it breaks through the Bald Mountains. Numerous tributaries are received on either side, all of which in their lower courses have the

characteristics of rivers of the plains. The fall of the French Broad from Brevard to Asheville, a distance of 50 miles, is 2.7 feet per mile.

On the north side of Grandfather Mountain are the headwaters of the South Fork of New River. This is the only stream in this region that flows northward. It drains about half of Watauga and Ashe counties, and flows through narrow valleys with steep mountain slopes on either side. After passing into Virginia it is joined by the North Fork of New River, and flows for 100 miles through that State, finally entering West Virginia, where it empties into the Great Kanawha, adding its waters to the Ohio.

From the southern slopes of Grandfather Mountain and the ridge between the towns of Grandfather and Blowing Rock flow the headwaters of the Yadkin. For the first few miles the stream is small and the fall very great, being through a rough and wooded country; but soon the river reaches the vast plateau known as the Piedmont Plain, and its valley opens out into a broad and fertile area, with numerous branches on either side, those from the south, which rise in the Brushy Mountains, being small, while those from the north, which rise in the Blue Ridge, are streams with large flow and considerable fall. The many tributaries add large volumes of water to the Yadkin, and as it flows to the east its discharge increases rapidly, until by the time the South Carolina boundary line is reached it has become one of the largest rivers of the Southeastern States. It flows for 130 miles through the State of South Carolina under the name of Pedee River.

The many springs on the southern slope of Grandfather Mountain join to form John River and Mulberry and Wilson creeks, which unite about 20 miles to the south and finally add their waters to Catawba River. The Catawba rises in the Black Mountains and flows east, descending from the high mountain sides to the level of the Piedmont Plain in frequent leaps of from 5 to 10 feet, and in one or two cases with vertical falls of 100 feet. From Oldfort, in McDowell County, it flows through the heart of the Piedmont Plain, receiving large tributaries from the north, notably North Fork, Linville River, Upper Creek, John River, and Lower Creek, all of which rise on the eastern slopes of the Blue Ridge, two of the chief tributaries, Linville and John, receiving their headwaters from the springs on the slopes of Grandfather Mountain. The river flows to the east, entering Alexander County, where it turns to the south and crosses the South Carolina boundary, after which it is known as the Wateree.

There are two rivers in this region which differ somewhat in their general characteristics from the streams described, viz, the Broad and the Saluda. Broad River is formed by the junction of the main Broad, the Green, the First Broad, and the Second Broad, and receives its headwaters from the slopes of South Mountain and the Blue Ridge. The tributaries, however, soon reach the flat, open plain, and uniting near the State line enter South Carolina near the western border of York County. Farther to the southwest Saluda River receives the

run-off from the Blue Ridge and flows for almost its entire length through South Carolina. Tugaloo River, which flows into the Savannah; Oconee River, one of the chief streams of Georgia and a tributary of the Altamaha; and the Chattahoochee, which waters in part the States of Georgia, Alabama, and Florida, also rise in the Blue Ridge.

SCENERY.

The scenery of the Southern Appalachian region is the grandest in the Eastern States. While in height the mountains can hardly be compared with the Rockies or the Alps, they far outstrip in height, massiveness, and extent the mountains of the Northeastern States. As one ascends Roan Mountain or Grandfather Mountain or passes through Hickory Nut Gap he is strongly reminded of the scenery of Switzerland, and might well imagine that he was on the Rigi or the Pilatus.

The mountains and valleys are covered with a luxuriant growth of forest trees, making one continuous bank of green from the bases to the summits of the highest peaks. (See Pl. IV.) With tireless energy the rivers have cut their ways through the massive ranges and formed stupendous gorges with bare, rocky walls almost vertical and hundreds of feet in height. These gorges, which confine the wandering streams, present views of rare grandeur and wonderful beauty. The charms of the Linville (see Pl. XXXVIII, Part II), the Cranberry, and the Watauga can not fail to arouse the wonder and admiration of all who visit them. Among the mountains and adjoining elevated plateaus there are a number of places where people seek rest and recreation during the hot months of the year. The visitors, however, are largely from the Southern States, and after spending a summer in these mountains the writer can but marvel that they have been so long overlooked by the people of the Eastern States as an ideal place to enjoy beautiful scenery and exhilarating mountain air. It can be accounted for only by the fact that so little has been known regarding the region, and that it is, unfortunately, rather difficult of access, there being few railroads except those used for lumbering, and the highways being execrable. These drawbacks, however, are rapidly disappearing, and the region would well repay a visit from the tourist or the seeker for health.

In general the mountain views are made up of a billowy succession of ridges (shown in Pl. V), the deep green of the mountains melting into the blue of the sky in the distance, while nearer at hand more subdued shades of green prevail, which in the valleys below merge into the soft, ripe yellows of the grain fields, with here and there a bare cliff or an area of red soil which stands out in sharp contrast. From the Unakas and to the north and west, where lies the beautiful Valley of East Tennessee, the views are of a different character. There the inequalities of surface are almost lost, and for miles the eye rests on a great plain dotted with light-colored cultivated areas and with green forest masses. Among the Unakas many balds occur, of which

TYPICAL FOREST-COVERED MOUNTAIN SIDE.

RICHLAND VALLEY FROM JUNALESKA MOUNTAIN, NORTH CAROLINA.

Whitetop is one of the most conspicuous and those of the Roan the most extensive and beautiful, consisting, as they do, of three or four peaks extending along the top of the mountain in a chain about 6 miles long. Dr. Mitchell many years ago said of Roan Mountain: "It is the most beautiful, and will best repay the labor of ascending it, of all our high mountains. With the exception of a body of rocks looking like the ruins of an old castle, near its southwestern extremity, the top of the Roan may be described as a vast meadow without a tree to obstruct the prospect, where a person may gallop his horse for a mile or two, with Carolina at his feet on one side, and Tennessee at the other, and a green ocean of mountains rise in tremendous billows immediately around him." Some of the highest peaks, however, are not bald, but are covered with a dark and dense growth of balsam and other evergreens. It is from a somber vegetation of this kind that the Black Mountains derive their name.

From Mount Mitchell a view into six States can be had. Although that mountain is the highest peak east of the Rockies, the views from it are not so fine nor so extensive as can be obtained from other mountains of less elevation, for the reason that it is surrounded by peaks with altitudes little less than its own, while Roan Mountain and Grandfather Mountain tower far above their surroundings, and from them magnificent views can be obtained in all directions.

Grandfather Mountain (shown in Pls. VI and VII) is probably the most massive of the Southern Appalachians, and is the culmination of the Blue Ridge. The scenery from it is unsurpassed. For many miles range after range of mountains spread out like the waves of the ocean, with opalescent clouds hanging down in the valleys below. In spring and summer there is the glint of the sunshine on the moist green of the leaves. In autumn the somber green of the balsam and spruce crowning the summits rises above the scarlet and golden glories of the foliage of the hard-wood trees, while in winter the great peaks lie cold and white, bare and forbidding. At every turn some new and beautiful thing is offered. Below the peaks myriad little brawling crystal streams dash in fleecy white over the ledges and around the bowlders that obstruct their courses (see Pl. VIII), or loiter in still pools where the rainbow trout lurk, while still lower are the green valleys hemmed in by the great mountains. On the slopes of Grandfather Mountain, from near the summit to the base, rise innumerable springs of pure, cold water, which uniting form rivulets that flow over rocky precipices and are finally joined into one of the several rivers which flow from its base. The mountain is covered with a heavy forest growth which has not yet known the woodman's ax. Nearly the whole of it, as well as its neighbor, Grandmother Mountain, is owned by the Linville Improvement Company, which controls 16,000 acres of the region, largely covered with forests, and, fortunately, lumbering is not their design. The company has laid out a town site in the valley of Linville River, at the foot of Grandfather Mountain, and intends to sell small tracts to

those who desire summer homes in the mountain region. In order that the springs which give rise to the streams on Grandfather Mountain may not be disturbed, 1,400 acres have been set aside as a public park, under five commissioners, one of whom is the State geologist and another the commissioner of agriculture of North Carolina.

The general contour of the mountains in the Southern Appalachian region is gentle, with smoothly rounded outlines (see Pl. IX), although occasionally sharp peaks are seen and here and there immense precipices are brought into view, especially in the southern portion of the region, as at Whiteside Mountain, one side of which presents a sheer face of naked rock 1,800 feet in height. (See Pl. X.)

CLIMATE.

As has been stated, the Blue Ridge may be considered the great water divide. The mountain region lies to the north and west, while on the east is the Piedmont Plain. The effect of the increased altitude upon the climate is apparent. The high plateau may be said to have cooler summers and more severe winters than the lower lands adjacent, the air is drier and more salubrious, the summer months are remarkably pleasant, the temperature varying somewhat with the altitude, but never too cold for comfort on even the highest mountain peaks. By choosing the proper locality one can obtain an average temperature corresponding to that of northern New England or to the warmer temperatures of the South Atlantic States. The mean annual temperature varies from nearly 60° F. at Salisbury, east of the mountains, to 49° F. at Linville, the latter being about the mean annual temperature of Boston and Chicago. On the mountain slopes the mean annual temperature is still lower. The seasonal temperatures of the mountain region are approximately as follows: Spring, 56°; summer, 73°; autumn, 57°; and winter, 40°. The following table gives the average monthly temperature, the mean annual temperature, and the seasonal temperatures as observed at the Weather Bureau stations in the mountain region:

Temperature observations in Southern Appalachian Mountains during 1900.

Station.	Average monthly temperature.												Mean annual temperature.
	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	
	Deg.	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*	*Deg.*
Biltmore	36.1	34.3	44.9	56.2	63.9	70.8	74.6	74.8	69.9	59.8	47.5	39.4	56.0
Charlotte	41.4	39.5	48.1	59.6	69.0	74.8	79.4	81.9	76.4	65.2	52.0	42.6	60.8
Henrietta	41.0	39.5	50.0	60.0	68.3	74.6	79.9	81.5	76.0	64.8	52.4	43.1	60.9
Hendersonville	36.6	34.6	45.1	54.4	62.4	70.2	73.4	75.4	70.4	62.6	50.0	40.5	56.3
Highlands	32.8	30.6	38.4	51.0	58.4	64.1	67.5	68.1	[a]63.6	56.2	45.3	35.8	51.0
Horse Cove	38.4	35.5	43.6	56.0	62.8	66.6	71.6	74.4	69.4	60.4	49.6	40.6	55.7
Linville	30.3	29.0	36.8	48.0	55.6	64.5	67.2	67.6	63.1	54.3	43.6	34.0	49.5
Morganton	.....	.....	.....	.....	.....	73.8	79.0	80.0	74.0	62.1	50.9	41.4	.....
Mount Airy	37.0	35.6	42.6	55.8	62.4	70.0	76.6	77.6	71.7	61.9	48.7	38.8	58.6
Marion	38.8	36.2	46.8	57.8	66.6	72.8	78.2	80.1	75.2	63.3	51.2	41.5	59.0
Marshall	33.8	34.6	43.2	54.6	64.2	72.0	75.8	76.5	[b]69.6	61.2	.....	.....	.....
Waynesville	35.2	36.1	43.6	52.6	61.0	68.5	71.8	71.4	67.2	58.4	44.0	37.5	53.9

[a] Record for three days missing. [b] Record for six days missing.

GRANDFATHER MOUNTAIN, NORTH CAROLINA.

CENTER, GRANDFATHER MOUNTAIN, NORTH CAROLINA (HIGH PEAK IN BACKGROUND), FROM PIXIE.

Temperature observations in Southern Appalachian Mountains, etc.—Continued.

Station.	Seasonal temperatures.				Latitude.		Longitude.		Elevation.	Length of record.
	Spring.	Summer.	Autumn.	Winter.						
	Deg.	*Deg.*	*Deg.*	*Deg.*	°	′	°	′	*Feet.*	*Years.*
Biltmore	55.0	73.4	59.0	36.6						2
Charlotte	58.9	78.7	64.5	41.2	35	13	80	51	808	22
Henrietta	59.4	78.7	64.4	41.2						
Hendersonville	54.0	73.0	61.0	37.2						1
Highlands	49.3	66.6	55.0	33.1	35	5	83	25	3,817	15
Horse Cove	54.1	70.9	59.8	38.2	35	0	83	6	2,800	6
Linville	46.8	66.4	53.7	31.1	36	5	81	51	3,800	4
Morganton		77.6	62.3		35	45	81	44	1,135	9
Mount Airy	53.6	74.7	60.8	37.1	36	30	80	40	1,048	10
Marion	57.1	77.0	63.2	38.8	35	30	82	5	1,425	5
Marshall	54.0	74.8								
Waynesville	52.4	70.6	56.5	36.3	35	29	82	58	2,756	4

Highlands, the highest station, is 3,817 feet in elevation, while several of the mountain ranges and peaks reach altitudes of from 5,000 to 6,000 feet, and their temperatures are lower than those given in the table. The following table gives the temperature extremes at a number of observation stations:

Temperature extremes in Southern Appalachian region.

Station.	Elevations.	Length of record.	Highest monthly mean.		Lowest monthly mean.		Highest observed.		Lowest observed.	
			Temperature.	Date.	Temperature.	Date.	Temperature.	Date.	Temperature.	Date.
	Feet.	*Yrs*	*Deg.*		*Deg.*		*Deg.*		*Deg.*	
Asheville	2,250	23	74.8	July, 1879	27.2	Jan., 1893	95	Sept. 15, 1897	[a]— 9	Jan. 16, 1893; Feb. 8, 1895
Chapel Hill	500	41	82.2	July, 1893	28.4	Jan., 1857	105	Aug. 10, 1892	— 1	Jan. 16, 1893
Greensboro	843	15	82.6	do	32.3	Dec., 1876	101	Aug. 10, 1896	6	Jan. 28, 1897
Highlands	3,817	15	70.9	July, 1878	24.4	Jan., 1893	86	June —, 1891	—17	Feb. 8, 1895
Horse Cove	2,800	6	74.4	July, 1893	28.5	do	93	Sept. 15, 1897	—13	Do.
Lenoir	1,186	26	77.7	July, 1877	27.3	do	95	July 18, 1887	—16	Dec. —, 1880
Morganton	1,135	10	80.0	July, 1868	26.4	do	100	Sept. 16, 1897	— 1	Jan. 16, 1893
Mount Airy	1,048	10	77.1	July, 1872	26.2	do	98	Sept. 28, 1891	—15	Do.
Mount Pleasant	650	12	79.1	Aug., 1896	29.9	do	98	June 29, 1889	— 4	Jan. 21, 1893
Murphy	1,614	12	76.9	July, 1878	28.5	Dec., 1876				
Salisbury	760	13	82.0	July, 1893	33.0	Jan., 1893	102	Aug. 10, 1896	5	Feb. 21, 1896

[a] Minus sign indicates temperature below zero.

PRECIPITATION.

The annual rainfall is copious, larger than anywhere else in the United States except on the northwestern coast, in Oregon and Washington. As might be supposed, it varies considerably in different parts of the high regions. The warm, moist winds from the east and south are deflected upward by the Blue Ridge, causing a cooling and consequent precipitation. In this way the yearly rainfall is greatly increased on the slopes of those mountains. At Highlands, in Macon County, the annual normal precipitation is about 72 inches and at Horse Cove about 73 inches. West of the Blue Ridge the annual rain-

fall is much less in the valley bottoms between the mountain ranges. For instance, a long record at Asheville gives a normal rainfall of about 42 inches, the smallest of any record of the mountain region. The normal at Waynesville, in Haywood County, is 46 inches. The average precipitation of the whole region may be considered to be approximately 53 inches. The following table gives the monthly, annual, and seasonal precipitation for 1900:

Precipitation in Southern Appalachian region during 1900.

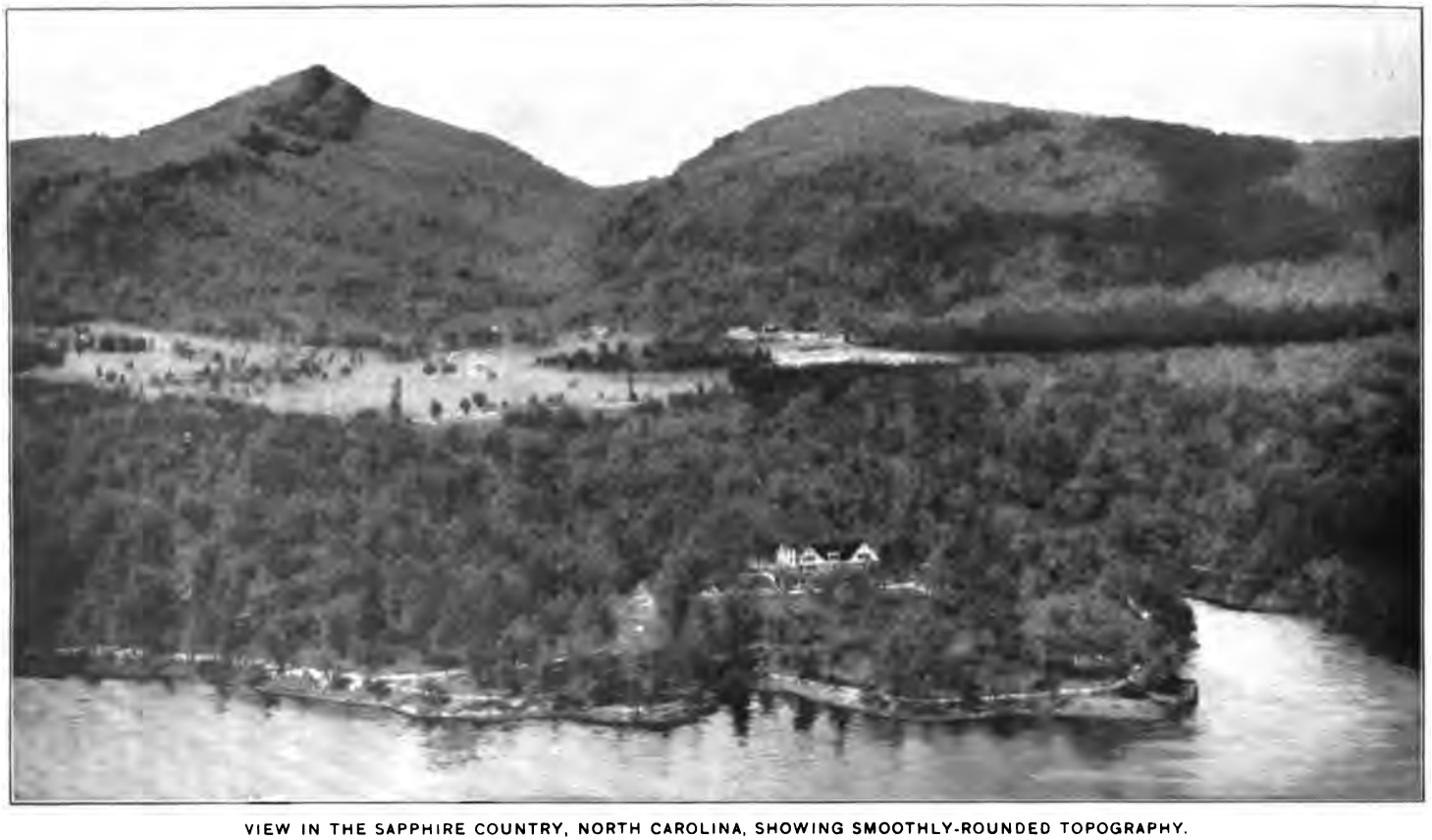
Station.	Monthly precipitation.												Mean annual.
	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
Abshers	3.35	7.50	4.92	4.89	2.93	9.28	7.43	4.14	5.46	8.73	5.15	3.35	67.13
Asheville	2.26	4.67	5.53	4.18	0.99	8.11	1.99	2.54	3.39	2.92	4.62	3.46	44.66
Biltmore	2.41	6.90	2.87	3.31	1.37	7.91	2.10	0.52	2.51	3.67	3.34	3.80	40.71
Bryson	2.85	7.72	7.33	4.67	1.21	6.31	2.88	4.48	3.02	2.87	4.80	4.76	52.90
Charlotte	2.15	5.25	5.28	5.32	2.11	7.31	3.55	3.05	0.73	3.41	3.85	4.83	46.34
Cherryville	3.31	7.01	5.65	7.55	3.34	6.39	2.25	2.61	2.01	2.29	4.04	4.80	51.25
Flatrock	.....	13.24	5.06	.....	.....	.....	.....	.....	.....	8.17	3.87	3.90	.....
Hendersonville	3.94	10.10	5.76	8.06	3.83	8.79	5.75	1.53	3.80	4.10	3.47	4.98	64.11
Henrietta	3.09	10.69	5.29	6.77	2.92	6.99	2.79	1.45	1.05	4.15	5.27	5.10	55.56
Highlands	5.82	13.84	7.10	10.20	1.67	19.29	8.04	1.95	4.99	6.00	5.03	7.53	91.46
Horse Cove	4.28	12.98	7.10	8.83	2.28	19.92	9.43	3.36	6.74	8.63	5.94	6.67	96.16
Linville	2.63	5.34	7.60	5.51	2.17	7.07	3.99	3.70	4.42	13.40	4.47	3.95	64.25
Maria	2.13	5.17	4.06	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Marion	3.59	9.22	6.65	9.70	1.96	10.50	3.52	2.70	3.48	9.69	4.04	4.74	69.79
Marshall	1.26	4.07	3.69	2.62	1.46	8.33	1.49	2.69	3.63	3.51	2.25	3.09	38.09
Mount Airy	2.35	4.00	*3.50	*3.67	1.02	8.56	3.52	2.50	4.12	4.04	3.10	3.38	43.76
Mount Pleasant	2.11	6.68	3.07	4.34	2.53	4.87	.....	.....	.....	.....	.....	.....	.....
Morganton	.....	.....	.....	.....	.....	5.97	2.65	1.15	2.10	3.20	2.26	4.40	.....
Mocksville	3.40	4.38	6.18	4.68	3.13	.....	2.88	2.07	2.08	3.04	3.31	3.32	.....
Murphy	3.55	6.45	7.07	4.83	2.19	8.87	4.04	2.78	3.19	5.19	5.22	5.45	58.83
Salisbury	3.22	4.52	5.02	4.98	4.12	4.81	3.52	1.79	1.60	1.90	2.10	6.35	43.93
Settle	2.82	5.34	3.30	4.30	2.40	5.57	2.43	3.95	3.56	2.99	3.08	4.51	44.25
Waynesville	2.38	6.97	6.00	6.41	1.01	7.64	3.55	2.25	2.49	2.12	3.57	4.08	48.47

Station.	Seasonal precipitation.				Latitude.	Longitude.	Elevation.	Length of record.
	Spring.	Summer.	Autumn.	Winter.				
	In.	*In.*	*In.*	*In.*	° ′	° ′	*Feet.*	*Years.*
Abshers	12.74	20.85	19.34	14.20	.....	.....	.....	.....
Asheville	10.70	12.64	10.93	10.39	35 37	82 30	2,250	22
Biltmore	7.55	10.53	9.52	13.11	.....	.....	2,150	2
Bryson	13.21	13.67	10.69	15.33	35 27	83 23	2,000	16
Charlotte	12.71	13.91	7.99	11.73	35 13	80 51	898	22
Cherryville	16.54	11.25	8.34	15.12	.....	.....	.....	.....
Flatrock	.....	.....	.....	.....	35 15	82 25	2,214	6
Hendersonville	17.65	16.07	11.37	19.02	.....	.....	2,167	1
Henrietta	14.98	11.23	10.47	18.88	.....	.....	.....	.....
Highlands	18.97	29.28	16.02	27.19	35 5	83 25	3,817	15
Horse Cove	18.21	32.71	21.31	23.93	35 0	83 6	2,800	6
Linville	15.28	14.76	22.29	11.92	36 5	81 51	3,800	4
Maria	.....	.....	.....	.....	.....	.....	.....	.....
Marion	18.31	16.72	17.21	17.55	.....	.....	1,425	5
Marshall	7.77	12.51	9.39	8.42	.....	.....	.....	.....
Mount Airy	8.19	14.58	11.26	9.73	36 30	80 40	1,048	10
Mount Pleasant	9.94	.....	.....	.....	35 28	80 28	650	12
Morganton	.....	9.77	7.56	.....	.....	.....	1,135	9
Mocksville	13.99	.....	8.43	11.10	35 51	80 34	651	4
Murphy	14.09	15.69	13.60	15.45	35 8	84 0	1,614	20
Salisbury	14.12	10.12	5.60	14.09	35 4	80 29	760	13
Settle	10.00	11.95	9.63	12.67	.....	.....	.....	2
Waynesville	13.42	13.44	8.18	13.43	35 29	82 58	2,756	4

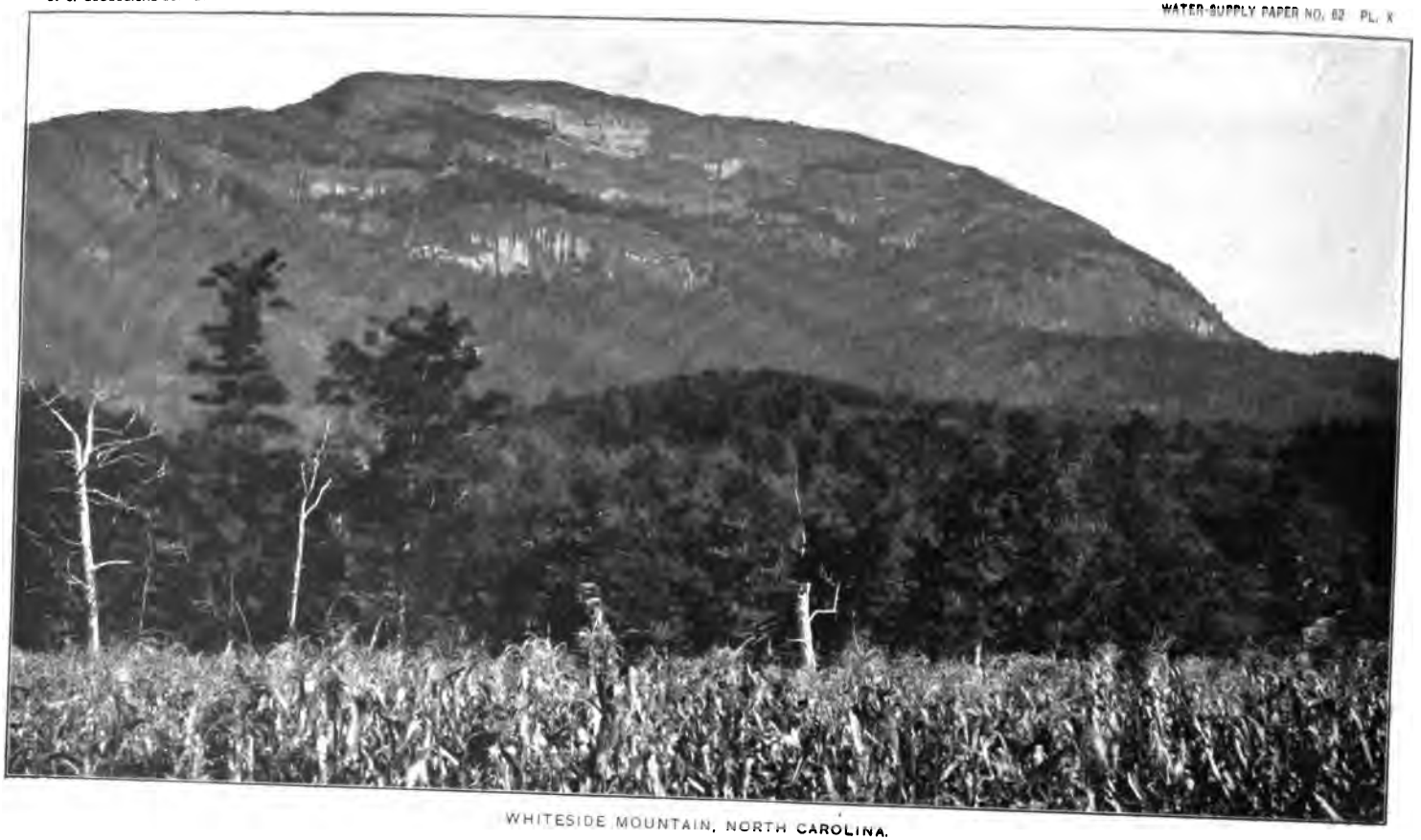
* Partly estimated.

Heavy rains occur at short intervals, which with the steep slopes cause rapid increase in the flow of the streams for a day or a few

SKYUKA FALLS, NORTH CAROLINA, A TYPICAL MOUNTAIN WATERFALL



VIEW IN THE SAPPHIRE COUNTRY, NORTH CAROLINA, SHOWING SMOOTHLY-ROUNDED TOPOGRAPHY.



WHITESIDE MOUNTAIN, NORTH CAROLINA.

hours, when the rivers as rapidly fall to their normal stage. Floods are frequently caused by the heavy rains. It is exceedingly difficult, however, to obtain measurements of the extreme high waters, for unless one is near the station at the time the water rises the river falls before he can reach there. A rainfall of 7.39 inches was recorded at Salisbury on June 10, 1883, and 6.01 inches at Highlands on February 8 and 9, 1891.

There is considerable snowfall during the winter months of the year, the average annual snowfall at a few stations being as follows: Asheville, 16 inches; Highlands, 22 inches; Lenoir, 11 inches; and Mount Airy, 12 inches.

The following table gives the greatest and least monthly precipitation:

Table showing greatest and least monthly precipitation in Southern Appalachian region.

Station.	Elevation.	Length of record.	Greatest monthly precipitation.		Least monthly precipitation.		Highest monthly average.	Lowest monthly average.
			Amount.	Date.	Amount.	Date.		
	Feet.	*Years.*	*Inches.*		*Inches.*		*Per cent.*	*Per cent.*
Asheville	2,250	23	[a]11.40	July, 1874	0.21	Oct., 1895	143	74
Charlotte	808	22	11.13	Mar., 1891	0.23	Nov., 1890	126	74
Highlands	3,817	15	20.20	Feb., 1891	0.25	May, 1883	135	79
Horse Cove	2,800	6	17.02	June, 1892	0.62	Oct., 1892	136	38
Lenoir	1,186	26	11.50	May, 1873	0.00	Nov., 1890	133	78
Morganton	1,135	10	11.20	Apr., 1878	0.20	Oct., 1892	129	67
Mount Airy	1,048	10	10.38	July, 1889	0.17	Nov., 1890	147	60
Mount Pleasant	650	12	10.27	Aug., 1887	0.28	Oct., 1892	142	66
Salisbury	760	13	16.14	do	0.13	Nov., 1890	128	67

FORESTS AND LUMBERING.[b]

Nearly the whole of these mountains was once covered with a magnificent growth of timber, which owing to its inaccessibility was long spared the woodman's ax. Now, however, since the forests of the North and the West have been denuded, the lumbering element has turned its attention to the Southern Appalachians, and the vast forests there are rapidly disappearing. Railroads have penetrated the mountains, and mills large and small have been located in the forested areas. One great railroad traverses the heart of the region, with a branch from Asheville through Macon and Cherokee counties. Lines have also been constructed up Doe and Nolichuky rivers, and a number of other lines have been surveyed, some of which will probably be built within a few years. Wherever a railroad is constructed the neighboring timber soon disappears, in consequence of the cheaper transportation. Most of the large mills are steam sawmills, and they are moved deeper into the forests as the supply of timber in their immediate vicinity is exhausted, the railroads being extended to them. Near the rivers the logs are splashed down the streams to the timber

[a] There is record of a greater amount than this, but it is not considered quite trustworthy.

[b] During the summer and fall of 1900 extensive investigations of the forests of the Southern Appalachian region were made by the United States Bureau of Forestry, Gifford Pinchot, forester.

pens of the mills below, thus saving the cost of railroad transportation or long hauls over rough and steep roads. Splash dams are constructed which hold back the water in dry seasons and float the logs over the rocky beds of the streams.

Notwithstanding the inroads that have been made on these forests, nowhere in the United States is there an equal area of land covered with so great a variety of valuable timber. The walnuts, tulips (poplars), and oaks grow to almost incredible size (see Pl. XI). In many localities white pine occurs in large tracts, growing to great heights (see Pl. XII) and furnishing as fine lumber as any of the pine forests of the country. Near the summits of all of the higher mountains the only growth is the balsam. Most of these trees are exposed to the cold and wind, and for that reason are small and twisted (see Pl. XIII, *A*), but where protected they grow to large size, especially in the Craggy and the Smoky mountains. Numerous varieties of rhododendrons grow on the slopes of many of the mountains, forming an almost impenetrable jungle. During the flowering season these present a most beautiful appearance, being often a mass of blossoms stretching as far as the eye can reach in every direction. Grandfather Mountain is particularly rich in this growth (see Pl. XIII, *B*), the chief species being *Rhododendron maximum*, *Rhododendron catawbiense*, and *Rhododendron vaseyi*.

Although the region still has the finest hard-wood forests in the country, the large tracts of wild cherry and black walnut which once flourished have entirely disappeared, and the mills are now sawing cheaper lumbers, such as oak, white pine, ash, and poplar. Not many years ago the supply of walnut was so abundant that old mountaineers tell of splitting rails from walnut logs and of burning or allowing to rot the walnut stumps which to-day would bring immense sums from veneering factories. The unfortunate feature of this lumbering is that there is no discrimination in the cutting. All of the trees, large and small, are felled, and if found not suitable for immediate use they are allowed to rot on the ground. In many places the lumber companies are recutting areas which have once been gone over, and are denuding them of even the smallest trees. Some of the companies saw anything that will make a plank. In the case of the bark gatherers the wastefulness is particularly deplorable. These men fell the trees—chiefly chestnut-oak and hemlock—for the bark, and after stripping them make no attempt to use the timber. Every year hundreds of cords of bark are hauled from these mountains, and each load means that some giant of the forest lies useless on its native soil. Near the railroads it is profitable to saw the timber and haul it to the station, but the natives find that they can strip the trees and haul the bark much farther than they can afford to haul the timber. It is a mournful sight to see these immense trees lying where felled, of no use to anybody, simply marking the wanton wastefulness of man.

POPLAR FOREST.

PINE FOREST.

A. WIND-DWARFED BALSAM FIR ON GRANDFATHER MOUNTAIN, NORTH CAROLINA.

B. RHODODENDRON THICKET, NEAR GRANDFATHER MOUNTAIN.

Lumbering on a large scale has been carried on for only a few years, but in addition to the large steam mills, which are moved deeper into the forest as the timber in their vicinity is exhausted, every little creek now has one or two small water-power sawmills cutting from 500 to 5,000 feet a day. Dry kilns are built and planers are put in so that the mills can turn out finished lumber. Although by the old methods fearful inroads were made on the forests, so thorough is the denudation by the new mills that it will not take them many years to exhaust all of the timber that is worth sawing.

The four largest lumber plants operating in this section are the Watauga Lumber Company, on Watauga River; the Empire Company, in the Shady Valley; the Ritter Company, at Pineola, on Linville River; and a new company with main yards at Huntsdale, Tenn., on the Nolichucky.

The Watauga Lumber Company owns almost all of the timber in the Watauga Valley. They have built five splash dams for the purpose of floating logs down to their mill. Two of these dams are on the main river, one at Shulls Mill and the other just above the mouth of Beaverdam Creek. On Beaverdam Creek there is a splash dam about 2 miles from the mouth, and during the summer of 1900 the company removed much of the timber from the lower part of the Beaverdam Valley. About 6 miles up Laurel Creek they have another splash dam, and are now cutting the timber in that region. The fifth dam is on Elk Creek, just below the big falls. They have not commenced lumbering there yet, but they own all of the timber. At Shulls Mill the company has built a tramroad up in the mountains to haul their logs to the river. They cut only the white pine and the poplar, because of the distance the logs have to be splashed. They now have thousands of logs all along the river from Shulls Mill to their mill below Elizabethton.

The Empire Company started work in the Shady Valley during the summer of 1900. They have put up a large mill and timber pen on Beaverdam Creek, and later will put in a dry kiln. The mill is to be run by steam. The Holston Valley Railroad is being built from Abingdon, Va., for the purpose of getting this lumber out. The railroad follows down the South Fork of Holston River to the mouth of the Laurel Fork, then up the Laurel Fork and Beaverdam Creek. This is considered one of the finest timber regions in the mountain section, consisting mostly of white pine and spruce, with a very little hard wood, mostly chestnut. The land being very fertile, the trees have grown to great size, being nearly 100 feet to the first limb. Up to the present time the timber in this valley has been almost untouched, on account of the long haul over the mountains to a railroad.

The Ritter Company, at Pineola, has had its mill in operation about a year. It is run by steam, and has a capacity of 50,000 feet a day. Their timber pen is on Linville River, and the logs are brought to it

by a narrow-gage railroad, which also carries the timber to Johnson City, Tenn., by way of Cranberry, N. C. The tract of this company, which contains some very fine white pine, extends from Pineola to Linville Falls, on both sides of Linville River, and includes most of the timber on Jonas Ridge.

The Ohio River and Charleston Railroad has been constructed from Johnson City, Tenn., up the valley of Nolichucky River as far as the mouth of Caney River, and a large lumber yard and shipping point have been established at Huntsdale, Tenn. A number of steam sawmills have also been built on the slopes of the Black Mountains. These mills are temporary structures and will be moved from point to point to avoid long hauls of the logs. The lumber is hauled to Huntsdale for shipment. Huntsdale has sprung up on the banks of the Nolichucky like a western mining town, and is not yet on maps of the region. The owners expect to extend the railroad very soon. It is said that they have bought 1,000,000 trees and are still increasing their purchases.

Several other companies are doing considerable lumbering. A company in Bristol has built a railroad to transport timber from the mountains south of Bristol across the South Fork of Holston River.

The many wood-working establishments on the Tennessee side of the mountains use considerable lumber, and close to the railroad on that side much soft wood is cut for the pulp mills in Bristol and other places.

Despite the great inroads on the forests in this region, many large areas have not been touched. The timber near the tops of all of the higher and steeper ridges still remains. This is particularly noticeable in the area between the South Fork of Holston River and the Watauga, where, except in the Shady Valley, which is now being cleared, all the timber that could easily be reached is gone, and only that at the tops of the steepest mountains remains. Three especially large areas, however, have not been cut, namely, Grandfather Mountain, the Black Mountains, and the long strip of land on both sides of Linville River. Grandfather Mountain is owned by the Linville Improvement Company, and it is not likely that they will permit any lumbering. The variety of trees in this area is greater than in the other regions, being hard woods near the base of the mountain and fir near the summit. The Black Mountains have escaped the lumberman only because of the difficulty of removing the logs and getting the lumber to market. Since the completion of the Ohio River and Charlestown Railroad to Huntsdale, however, several mills have started work around the bases of those mountains, and it will not be long before the timber is cut well up the sides.

On both sides of Linville River, from just below Linville to Beech Bottom, there is a very large strip of land containing exceptionally fine timber which has not been cleared of even the most valuable

trees. The upper end of this strip, however, is owned by the Ritter Company, and they are clearing the area, as already mentioned. Their tract extends from just below Linville nearly to Linville Falls, and contains some especially fine white pine. The next strip, extending from a half mile above the falls to 3½ miles below them on each side of the river, and containing 51,000 acres, is owned by the Morganton Improvement Company. The next lower area, running down the river to Beech Bottom, belongs to the Cheever Improvement Company. The two latter tracts are very rich in white pine, poplar, ash, oak, hemlock, spruce, and the linn or linden.

Three railroads have been surveyed to run through this district—one from Bristol to Lincolnton, another from Cooks Gap to Lenoir, and the third from Collettsville, on John River, to Cranberry, to connect with the narrow-gage railroad running to Johnson City, Tenn. If these railroads are built the timber in the vicinity will soon be cut, leaving the ground bare, as it is along the other roads.

The unfortunate feature of the lumbering is that the ground is completely stripped of trees and then is left without cultivation. The slopes are often too steep for successful farming, and in many places the top soil is washed off and the hillsides become more or less gullied by the water rushing down the mountains.

Great as has been the havoc wrought by the lumberman, his part in the forest destruction has been small when compared with that of the clearing of the land for agricultural purposes and with forest fires. Too often the farmer, instead of trying to improve the soil in the valley, makes additional clearings on the mountain sides. Owing to the steepness of the slopes, the productiveness of the hillside fields is short lived. After the trees have been girdled and the underbrush destroyed the land can be planted in corn for one or two years, then in grain for a year, and then in grass for one or two years, after which it can be used as pasture land for a year or two, until, with increasing barrenness, the grass gives place to weeds and the weeds in turn to gullies.

Forest fires have been one of the great curses in the Southern Appalachians, as elsewhere in the country. They were of frequent occurrence in the days of Indian occupation. Thus they have preceded the lumberman, have accompanied him, and have followed in his wake, and their work has been rendered far more destructive by the lumberman leaving brush scattered among the remaining growth in such a way that in the burning it has fed the fires.

In some regions fires have entirely destroyed the forests, especially where the soil was thin and composed largely of humus. The burning of the humus has resulted in the remaining soil being soon washed away, leaving the trees standing on the bare surface of rock to dry out and die. In other places fires have destroyed the undergrowth and the larger trees have been burned near the roots in such a way

as to cause their destruction. Repeated fires in the undergrowth have exterminated the grasses and other forage plants over large areas, so that instead of improving the pasturage, which is frequently the object of starting the fires, the result has been in the course of years its almost total destruction.

That the burning of the humus and undergrowth in the forests seriously affects the flow of the streams anyone who has been in a forest during a heavy rain storm will admit. In the virgin forest the raindrops are caught by the underbrush and pass downward through the humus into the less porous soil and the rock fissures beneath, to reappear weeks and months later in the form of numberless springs. But where the underbrush and humus have been burned away much less water soaks into the soil, most of it flowing down the surface with a velocity varying with the slope, washing the soil into small furrows and gullies, causing the rapid accumulation of the water into brooks, and resulting in floods in the larger streams in the valleys below.

In New England and many of the Northern States the numerous lakes and glacial deposits of sand and gravel spread out over the hills and valleys of that region serve as a storehouse for the water and materially assist the forest cover in preserving uniformity in the flow of the streams. Indeed, they would accomplish much in that direction were the forest cover entirely removed. But in the Southern Appalachian region there are no lakes and no glacial gravels and sands, hence the water storage depends entirely upon the forests and the soil.

SOIL AND VEGETATION.

Besides the actual reduction of the earth's surface according as the rocks differ in susceptibility to atmospheric agencies, the region has been profoundly affected by the soils which the rocks have produced, for on the soils the character and amount of the vegetation are largely dependent.

The soil is naturally deep and fairly fertile even to the mountain tops, while the valleys, which have been cleared, are remarkable for their fertility. In the valley of each little mountain stream can be seen the small cabins of the mountaineers, who cultivate the narrow tracts of land close to the river and often attempt agriculture on the steep slopes of the mountain sides. Pl. XIV gives views of two characteristic mountain homes. In these houses the natives live on from generation to generation, seemingly without desire for change or betterment. When the eldest son is married he is given a portion of his father's land, which he in turn attempts to clear and cultivate, managing to eke out a scanty existence, and being, like his forefathers, well satisfied with his surroundings and his condition in life. Fruits and vegetables grow abundantly and to large size, and would no doubt be cultivated much more were it not for the lack of means of transportation. The entire region is well adapted to stock raising, which is

A.

B.

TYPICAL MOUNTAIN HOMES.

SPRING ON BLACK MOUNTAINS, SHOWING DENSE PLANT GROWTH.

one of the chief industries. Years ago General Clingman wrote: "Horses and horned cattle are usually driven out into the mountains about the first of April and brought back in November. Within six weeks after they have thus been put into the range they become fat and sleek. There are, however, on the top and along the sides of the higher mountains evergreen and winter grasses on which horses and horned cattle live well through the entire winter. Such animals are often foaled and reared there until fit for market, without even seeing a cultivated plantation." This custom of turning the stock loose on the mountains still continues; and in recent years considerable attention has been given to fine stock breeding.

Many varieties of shrubs and flowering plants abound, and the region should prove a Mecca for botanists. Pl. XV (a view on the Black Mountains) will give an idea of the great variety of ferns and plants with which the mountain slopes are covered. In the foreground is one of the cool springs for which the region is noted.

According to Mr. Arthur Keith, of the U. S. Geological Survey, "the moist atmosphere is conducive to the rapid decay of the rocks, which break up chiefly under the attack of rain, frost, the roots of the trees, the underground waters, and organic acids. At first decay works in along the various partings, resulting in the loosening of large masses, which gradually become smaller, until finally nothing is left of them except clay and the more obdurate bits of rock. The rocks reach the surface over only very small patches, while in places the disintegration attains a depth as great as 50 feet. On sloping surfaces the loose material is maintained in its place solely by friction. When this is lessened or overcome from any cause, the residual matter, be it clay or rock fragments, slides down the slope until the friction is again sufficient to retain it in one position. Thus are formed immense deposits washed down from steep slopes and accumulated in the hollows and flatter places. This material gradually works its way downhill, as it is pushed along by the freezing of the water, or is rendered more unstable as the water transforms it into mud. Eventually it finds its way into the streams and is carried by slow stages into the sea.

"The chief agent which checks this process of removal is the forest cover, even though the penetrating roots and the acids due to vegetation induce rock decomposition. These same roots, however, hold the loose material in place and check its tendency to slide downhill. With this assistance loose soils are upheld on slopes fully double those which they could maintain unaided. Besides this direct hindrance to the waste of slopes by increased friction, the action of the forests is as great in another way. Loose material is washed downhill during rain storms by even the tiniest rivulets.[a] In open fields these gather in a

[a] Pl. XVI, *A*, shows the starting of such a wash in a deforested area and illustrates the way in which this wash is checked by the growth of trees higher on the mountain side. H. A. P.

few minutes, and form deeper and deeper channels with each succeeding storm, finally removing the loose material down to the bare rock. This process is almost prohibited by the network of roots and the cover of leaves, both living and dead, and the water concentrates into rivulets by seeping through the soils so slowly that it carries no sediment. The waters finally drain off in the hollows and small streams whose channels have been fitted by long use to withstand the attacks of rushing water.

"Countless illustrations of this process can be seen during any rain storm. Streams which drain considerable areas of cleared land rise fast and become turbid with mud. Those which drain areas protected by forests rise much more slowly, and by comparison the water could be called clear, except in violent storms. This result is of course most striking at the very headwaters, the little streams rising in the fields and in the woods. The effects of this work are seen in the innumerable gullies which gash fields left to the elements for any time. In fact, unless checked by the most constant attention these gullies soon strip off the soil and clay and ruin the fields.[a] In the forests, on the other hand, one rarely sees a slope of soil not covered with vegetation, and it is only along the immediate banks of the streams that raw slopes of loose material are exposed. In short, in this region of deep residual soils the influence of the forest is paramount. It is a fact well known among the mountaineers that the soils are far more fertile when first cleared from timber than ever again. It is equally well known among the farmers along the river bottoms that the same crops have been planted there with equal success for scores of years. These latter soils, however, are refreshed from time to time by the overflowing waters, which have swept off fertile materials from the steeper slopes above. The natural fertility of the mountain soils is very great, as is abundantly shown by the dense and luxuriant forest growth. The pristine strength of the soil soon wanes in the clearings, however, and there ensues a loss which is permanent for at least a generation. To convince one's self of the existence of this condition it is only necessary to visit the region.

"In addition to the loss inflicted by forest cutting upon the steep slopes themselves great damage also results to the lands lying farther down the streams. The deep clays and underlying rocks form a kind of gigantic sponge which stores up water during its plenty. When the forests are stripped away the waters collect and run off with vastly greater speed, and much evaporates, so that not only is less stored up, but the discharge is more irregular and temporary. Destructive floods result and droughts are wider spread. Thus, viewed from the standpoint either of utility or beauty, these unrivaled forests are the keystone of the arch."

During high floods the rivers carry enormous quantities of sand and

[a] See Pls. XVI, *B*, and XVII. H. A. P.

A. VIEW SHOWING BEGINNING OF WASH ON MOUNTAIN SIDE.

B. VIEW OF DEFORESTED HILLSIDE, SHOWING EFFECT OF EROSION.

WATER-WASHED GULLY IN DECOMPOSED GNEISS, McDOWELL COUNTY, N. C.

clay washed from the mountain sides. This material is deposited in great beds upon the cultivated lands along the rivers below (see Pl. XVIII, *A* and *B*), making future tilling impossible and ruining immense areas of arable land.

Inasmuch as the rivers are chiefly dependent upon their headwaters for supply it is impossible to overestimate the importance of preserving the forest cover on the mountain sides.

MINERAL RESOURCES.

No effort will be made to describe in detail the mineral resources of the region. The geological surveys of the various States and of the United States have published considerable literature on that subject, and further studies of it are now being made. Stated briefly, corundum abounds in certain localities. The mica of Yancey and Mitchell counties is widely known as among the best in the world, the deposits being so extensive as to furnish a large part of the world's supply. In a number of counties iron occurs in large quantities, and copper and other minerals have been mined to some extent. In the descriptions of the various drainage areas mention will be made of the more important mineral resources of specific localities.

HIGHWAYS.

The highways of the region are bad, having steep grades and being poorly surfaced. In many localities practically no work is put on the roads, and during certain seasons of the year they become almost impassable to wagons. This is largely due to the neglect of the inhabitants, for in most parts of the mountain districts excellent road materials exist, and with proper care and intelligence the highways could be maintained in good condition at moderate expense. Upon the mountain sides the rain water is allowed to run in the road bed, soon washing out great gullies and exposing the rocks, so that a horse is obliged to pick his way from side to side with great care and the rider to be constantly on the alert to prevent accident. Such a road is shown in Pl. XIX, *A*. The highway from Marion, N. C., to Sprucepine, illustrated in Pl. XX, is a typical mountain road of this region over which a wagon can pass, but with difficulty. In many cases, in order to avoid cutting a road on the slopes of the mountains, the stream bed is used as a highway, although usually exceedingly rough and at the time of high water dangerous to the traveler. Pl. XXI illustrates a road bed which has for years been used as a highway. Farther down the river valleys, where clays are more prevalent, the roads are often exceedingly muddy, it being a common occurrence for the wagons to sink hub deep into the mud. (See Pl. XIX, *B*.) There are a few remarkable exceptions, however, as, for example, the toll road from Linville around the base of Grandfather Mountain to Blow-

ing Rock, known as the Yonahlossee road and shown in Pl. XXII, and the road between Blowing Rock and Boone, both of which are excellent in grade and surface and show what can be done when the materials at hand are used with skill.

DRAINAGE BASINS.

In the course of the examination of the watersheds and the general investigation of the flow of the streams in the Southern Appalachian region which were carried on during the summer of 1900, many measurements of flow were made on the larger streams and on most of their upper tributaries, the results of which are contained in this report. The small Price meter was used in making measurements. There being few bridges in the region most of the measurements were made by wading. It was therefore impossible to make gagings of many of the streams at the time of high water.

In some respects the season was peculiar. Rain was abundant during June and the streams were moderately high during the early part of the summer. Later, however, very little rain fell, and most of the rivers and their tributaries were at an extremely low stage, as low, in fact, as they have been for a number of years. An effort was made to make more than one measurement at the same point on each stream. When the first measurement was made a bench mark was established, and the relative height of the water surface was measured at each successive gaging. Examinations were also made for high-water marks, and when the annual fluctuations of a stream could be determined they were noted. By means of these data a knowledge of the flow of the streams at various stages and of the relation that exists between the rise of the streams and their discharge can be obtained, though of course the only definite information we have is the discharge at the time of measurement.

On the larger streams gaging stations were established, as is the custom of the Survey, the height of the water surface being read daily on the gage and recorded by a local observer, and the measurements, which were made as often as practicable, being referred to the same gage. With these data a curve was plotted, using the gage readings as ordinates and the stream discharge, in cubic feet per second, as abscissæ. From this curve, the mean of the daily gage readings being known, the approximate daily discharge was interpolated. This method is described in detail in the annual reports of the Survey and in Water-Supply Paper No. 56.

The great difficulty encountered at these stations, which are on mountain streams, was to obtain measurements at the time of high water. After a rain the rivers rise rapidly, and as they fall as quickly, unless a person is near the station the high water will have passed before he can reach the point of measurement.

A. SAND AND CLAY DEPOSIT IN VALLEY.

B. SAND DEPOSITED UPON FARMING LAND BY RIVER FLOOD.

A. WATER-WASHED COUNTRY ROAD IN MITCHELL COUNTY, N. C.

B. UNIMPROVED ROAD IN VALLEY.

The following is a list of the gaging stations established in the basin:

Gaging stations established during 1900 on streams in Southern Appalachian region.

Stream.	Location.	Date established.
		1900.
New River	Oldtown, Va	August 5.
South Fork of New River	New River, N. C	July 29.
North Fork of New River	Weaversford, N. C	Do.
Yadkin River	Siloam, N. C	August 3.
Catawba River	Morganton, N. C	June 19.
John River	do	Do.
Linville River	Bridgewater, N. C	July 3.
Broad River	Dellinger, S. C	August 30.
South Fork of Holston River	Bluff City, Tenn	July 17.
Watauga River	Butler, Tenn	August 11.
Roan Creek	do	Do.
Elk Creek	Lineback, Tenn	August 5.
Nolichucky River	Chucky Valley, Tenn	September 20.
Pigeon River	Newport, Tenn	September 4.
French Broad River	Oldtown, Tenn	Do.

Besides the foregoing stations, which were established during the summer of 1900, the following gaging stations have been maintained for several years upon streams flowing from the Southern Appalachian Mountains:

Regular gaging stations of the Geological Survey on streams flowing from the Southern Appalachian Mountains.

New River at Radford, Va., and at Fayette, W. Va.
James River at or near Glasgow, Buchanan, Cartersville, and Holcomb Rock, Va.
Roanoke River at Roanoke, Va., and at Neal, N. C.
Dan River at South Boston, Va.
Staunton River at Randolph, Va.
Yadkin River at Salisbury and Norwood, N. C.
Catawba River at Catawba, N. C., and at Rockhill, S. C.
Broad River (of the Carolinas) near Alston, S. C.
Saluda River at Waterloo, S. C.
Tallulah River at Tallulah Falls, Ga.
Tugaloo River near Madison, S. C.
Savannah River near Calhoun Falls, S. C., and at Augusta, Ga.
Oconee River near Dublin, Ga.
Chattahoochee River at Oakdale and at West Point, Ga.
Coosawattee River at Carters, Ga.
Oostanaula River at Resaca, Ga.
Coosa River at Rome, Ga., near Riverside, Ala., and at locks Nos. 4 and 5, Alabama.
Toccoa River near Blueridge, Ga.
Nottely River at Ranger, N. C.
Hiwassee River at Charleston and Reliance, Tenn., and at Murphy, N. C.
Tennessee River at Chattanooga and Knoxville, Tenn.
Little Tennessee River at Judson, N. C.
Tuckasegee River at Bryson, N. C.
French Broad River near Asheville, N. C.

These stations cover every stream rising in the Southern Appalachian Mountains. Results of measurements will be found in the annual reports of the Survey.

HOLSTON RIVER.

PHYSICAL FEATURES.

The areas drained by Holston River comprise the basins of the North, South, and Middle forks of that stream, the Watauga, the Nolichucky, and the French Broad, including parts of southwestern Virginia, eastern Tennessee, and western North Carolina. The river is one of the largest of the streams which form the great Tennessee River. It rises along the western slopes of the Blue Ridge, in Smyth and Bland counties, Va., in three forks, known as the North, Middle, and South forks, respectively. The North Fork, from its position, receives no tributaries rising within any of the areas proposed for the projected Appalachian National Park, and for that reason, in view of the very large area necessary to be covered during the field season and the limited time in which to perform the work, it was not investigated. The areas drained by the Middle and South forks were quite thoroughly studied, and many direct instrumental measurements were made of their flow and of the flow of all streams tributary to them whose discharge was sufficiently great to admit of the use of a current meter, the minimum limit being, roughly, a little less than 1 cubic foot per second, depending largely on the form and character of the bed of the stream.

The physical conditions of the drainage basin vary greatly, the character of the country ranging from the gently rolling plain of the South and Middle forks, with its smooth, rounded, and grass-covered hills, to the grandest and mightiest mountain masses to be found east of the Rocky Mountains, such as the Unakas and the Black Mountains, with their numerous peaks rising more than 6,000 feet above sea level, and with steep and rocky slopes still clad in virgin forest. There are wide variations in the soil and in the general geologic conditions and structure, considerable variation in temperature and rainfall, and still wider variations in the character of the streams of the area, which include the brawling mountain torrents fed by perpetual springs, the puny wet-weather streams of the slate country, and the subterranean streams of the limestone regions. The entire area is part of the great Mississippi slope, of which the eastern boundary is formed by the Blue Ridge Mountains, on which all of the streams of this area rise, those of Virginia flowing to the southwest, through the great Valley of East Tennessee, those from North Carolina flowing to the northwest, through the Unakas, in grand and deep gorges and down the valley slopes to their union with the main stream.

The Unaka chain, the most prominent natural feature within the

MOUNTAIN ROAD NEAR SPRUCEPINE, N. C.

ROAD IN STREAM BED.

area, is a long range, the most massive of the Appalachians, its high crests forming the boundary between North Carolina and Tennessee. It is for the most part one single ridge, but occasionally it spreads out into a series of from two to four parallel ridges. The chain is continuous except that it is intercepted by the deep and rocky cuts of the tributaries of the Holston and the Tennessee. In Virginia it unites with the Blue Ridge. It forms large parts of Johnson, Carter, Washington, Greene, Cocke, and Unicoi counties in Tennessee. In Johnson County the ridges lie in such a manner as to completely encircle the great cove of the county, and in Carter County they nearly inclose the valleys. It has been said that the chain is a belt of parallel ridges, but in most of the Tennessee part of it the ridges are two in number, one being the main axis of the chain, the other lower and lying along the foot of the slope, though generally separated from the main range by long coves. This typical character does not always hold good, however, the greatest departure being in the country to the northeast of French Broad River.

In the northeastern corner of the State, north of Watauga River, in Johnson and Carter counties, the Unakas divide into three distinct ranges separated by wide and beautiful valleys. Seen from some points these ridges appear parallel, but in reality they are convergent toward the north, and near the Virginia line the Holston and the Iron mountains, the most western of the diversions, converge, and farther on, in Virginia, the two ranges unite in the long chain known as the Iron Mountains. The most easterly of these three ranges is the Stone Mountains, a long series of crowded ridges, along the crest of which runs a portion of the State line, extending from south of the Watauga and culminating in the grand and conspicuous summit of Whitetop. The middle range is the Iron Mountains, a long, straight ridge extending through Johnson and Carter counties—a portion of it forming for a long distance the boundary line between those counties—being separated from the Stone Mountains by the valley lands of the former county. Watauga River and Doe River have cut through this range, but it continues to be well defined until the southern part of Carter County is reached, and there it sinks away. South of the Watauga it is separated from the mountains on the east by a long and narrow valley known in its wider portion as Doe River Cove. The last and most westerly of the ridges is the Holston Mountains, which run out abruptly from the other ridges and terminate as abruptly a few miles north of Elizabethton, Tenn. They are separated from the mountains on the east by the curious, very elevated basin called Shady Valley and by the valley of Stony Creek.

As a rule the Unaka ridges are forest clad. The higher summits, however, are frequently destitute of trees, owing perhaps to the high altitude and the consequent low temperature, but more probably to peculiarities of the soil. Such summits are called balds. Sometimes

they are a mile or more in diameter, and sometimes a chain or succession of them occurs along a ridge, forming a continuous bald for several miles. Roan Mountain is a bald of the latter class, and there are several others like it in the range. The most magnificent views in the mountains are obtained from these peaks.

Lying to the west of the Unakas is the great valley known as the Valley of East Tennessee. This broad and beautiful basin is a southward continuation of the famous Valley of Virginia. In Tennessee it has an extreme width of more than 50 miles. It is drained by the Holston and its tributary streams. The portion of the valley covered in the course of this investigation embraced parts of Sullivan, Carter, Johnson, Washington, Greene, and Cocke counties. The topography is composed largely of a series of parallel ridges, the axis extending in a northeast-southwest direction, making the country very rolling when viewed transversely. One of the most marked peculiarities of the region is the short and narrow ridges of slate which are apparent here and there over the area, sometimes occurring in short chains of slaty knobs. In Washington, Greene, and Cocke counties the valleys partake of the nature of the ridges and are short and broken. There are wide variations in the width of the stream valleys, some being sharp and V shaped, others several miles in width and very beautiful and fertile. One of the largest of the valleys is in Johnson County—Johnson County Cove, as it is sometimes called. Its form and position can be seen by reference to almost any map of the area. Below Mountain City it is divided lengthwise by Doe Mountain, an isolated sandstone ridge, but the parts are united again in the valley of the Watauga, which is said to have a larger area than any other valley of similar elevation in the State. It narrows to a point a short distance from the Virginia line, and is entirely inclosed by mountains, the Stone Mountains being on the east and south and the Iron Mountains on the northwest.

Lying between the Holston and the Iron mountains, just before they unite in Virginia, is the elevated basin called Shady Valley, also situated in Johnson County, and being much higher than the great valley just described, but having a much more limited area. The elevation is so great that the flora partakes of the character of that found in the northern regions of Canada. Iron of good quality and very fine white pine and spruce are found here. This valley is more fully described on pages 65 to 66, in the description of the area drained by Beaverdam Creek.

The rivers of the Valley of East Tennessee are wide and shallow, the waters clear and beautiful, and the tributaries numerous. There are two general directions of flow, the tributaries flowing to the northwest or the southeast and the main streams flowing to the southwest. The valley floor throughout is very level to gently rolling, composed of small and rounded hills with gentle, grass-covered slopes, leaving

YONAHLOSSEE ROAD, AROUND THE BASE OF GRANDFATHER MOUNTAIN, NORTH CAROLINA.

broad areas of level meadows or bottom land between them and dotted over with small tracts of hard-wood trees. From this general level the transverse ridges as a rule rise gently, although they are sometimes very rough and rugged and are almost entirely forested.

The area drained by Holston River in Virginia is entirely within the limits of Washington and Smyth counties, being the southeastern half of each county. The extreme southern and southeastern parts of the area are covered by the northward extension of the great Unaka chain known as the Iron Mountains. The extreme eastern part is covered by the slopes of the Blue Ridge and its outliers, the Pond and the Brushy mountains. On the north it is closed in by the slopes of Walker Mountain, a long ridge which separates the watersheds of the North and South forks of the stream. The general characteristics of these mountain areas are similar to those previously described for the Unaka chain in Tennessee, except that the peaks rise to less heights and are completely wooded. The geologic structure is, however, different, many of the mountains being capped with sandstone, the prevailing rock of the valley floor being limestone. The valley itself is much more broken, and in its upper part contains a much smaller portion of cleared land than the areas farther to the south, the natural consequence of the changed topography. However, the strip of level land bordering the South Fork on the south, the entire area between the South and Middle forks, except the slopes of the Pond and the Brushy mountains, and the area to the north of the Middle Fork as far as Walker Mountain are well situated for agricultural and stock-raising pursuits, are almost entirely cleared, and are in a high state of cultivation, being held at a very high valuation.

The part of the watershed in North Carolina, being the areas drained by the Watauga, Nolichucky, and French Broad rivers, is included in the counties of Watauga, Yancey, Mitchell, Madison, Buncombe, Henderson, and Transylvania, and is described at length in connection with the drainage basins of those rivers. The last four counties comprise the watershed of the French Broad. The first three counties—Watauga, Yancey, and Mitchell—occupy the entire width of the transmontane plateau lying between the western slopes of the Blue Ridge and the Unakas, and their surface is a bewildering confusion of mountain chains and spurs extending in every direction, without order or plan, and inclosing short and narrow valleys and inconsiderable areas of cleared land, except along some of the larger streams.

One of the distinguishing characteristics of the whole basin drained by Holston River is the occurrence of small closed basins or sinks, which are found in great numbers on the low divides between the various tributary watersheds. They are so numerous, in fact, that in many localities it seems impossible that any of the rainfall over areas of a square mile or more can find its way into the streams. Certainly

there are no channels visible, and in many cases water was seen standing in pools from 50 to 100 feet in diameter, indicating that there is no subterranean passage through which the water finds its way to the streams. Other sinks are dry, except after heavy rains. In some instances the farmers have rendered the bottoms of these natural basins impervious, and the collected water is used for cattle.

Springs are numerous over all the basin, ranging in size from a discharge of several cubic feet per second to less than a gallon per minute. Many of the smaller streams seem to be fed entirely from this source. In this connection may be noted the fact that a number of streams which at some point in their course sink below the surface of the ground, after flowing there for distances varying from a few yards to a half mile or more reappear on the surface. Some streams were noted which while discharging no water into the main stream carried a considerable quantity a short distance above their mouths, the water sinking gradually into the earth as the river was approached. It is said that the Middle Fork loses a quantity of water in this way, and from the character of the country rock this seems by no means improbable.

RAINFALL.

Little definite information can be given regarding the annual rainfall in this basin, but it is well known that throughout the region there is no lack of moisture, showers frequently falling on the mountains when there is not a cloud over the valley. The rainfall in the valley to the west is between 40 and 45 inches per annum, and that on the mountains is certainly greater. Throughout all the area covered by the investigation there is a lack of records whereby the rainfall can be even approximately determined, most of the records obtainable being very fragmentary. Those at Knoxville best represent the average condition prevailing over the valley, though the Chattanooga records may be of service in determining the average rainfall. The maximum precipitation recorded at Knoxville is 73.8 inches per annum, which is 146 per cent of the mean, and up to 1896 the minimum was 37.4 inches, or 74 per cent of the mean. At Chattanooga the maximum is 68.1 inches per annum, or 126 per cent of the mean, and the minimum is 37.2 inches, or 69 per cent of the mean. It may be stated that the variation between the maximum and minimum rainfall is at least as great as this throughout the region, the precipitation in dry years being somewhat less than 50 per cent of the mean.

Droughts are rare and as a rule of short duration. The most notable one occurred in the summer and autumn of 1900, when throughout the entire country, both in the valleys and on the mountains, the drought was very severe and long continued, producing the lowest known stage of flow in all of the streams. During the winter the higher summits are almost entirely covered with snow

AGRICULTURE.

As might be expected from the comparatively scanty population and the inadequate transportation facilities, agriculture and stock raising are the principal pursuits. In the valley of Holston River, where the country is comparatively level, there are many fine farms, which are held at a high valuation, and the community seems extremely prosperous. Although the areas drained by the Watauga and the Nolichucky are rough and mountainous, yet the lower slopes afford a fine cattle range, and the valleys are sufficiently extensive to produce the necessities of life for the inhabitants.

MINERALS.

The mining possibilities are very large, although little has been done to develop this source of wealth. In the localities where mines have been opened the work seems to have been carried on in a very spasmodic way. Iron ore of great purity is found in abundance in many places, and has been mined to a considerable extent at some localities, the ore being reduced at the furnaces at Bristol, Johnson City, Embreville, and Cranberry within the basin, or shipped to Pulaski and near-by points outside of it. Copper, lead, zinc, fluorspar, gypsum, gold, salt, barytes, mica, corundum, and gem stones all occur in quantity, and some have been mined at large profit.

LUMBER.

The lumber interests also are of great importance, the area containing many large tracts of fine timber, from which several large sawmills draw their supplies, while small portable mills are found over all the area. A large amount of tan bark is stripped near the railroads, the stocks being sometimes worked into cord wood, but more often allowed to rot where they fall.

TRANSPORTATION.

The transportation facilities over the greater part of the area are pitifully inadequate. The Norfolk and Western Railroad skirts the northern edge of the basin of Holston River proper, the Knoxville branch of the Southern Railway follows along the French Broad, there is a narrow-gage road from Johnson City to Cranberry, a small standard-gage road has been constructed from Bristol to Butler and is now being extended up the valley of Roan Creek toward Mountain City, while another road is being built from Abingdon to Damascus, from which place it will extend up Beaverdam Creek and into the Shady Valley, and the Ohio River and Charleston Railroad has recently been extended along the Nolichucky as far as the mouth of Caney River. In by far the greater part of the area, however, the only means of

transportation is by wagons drawn over the mountain roads, which are generally very rough and steep.

SOUTH FORK OF HOLSTON RIVER.

PHYSICAL FEATURES.

The South Fork of Holston River rises on the western slopes of the Blue Ridge, in Smyth County, Va., between the slopes of the Brushy Mountains on the north and the Iron Mountains on the south. It is formed by the junction, in a broad stretch of valley land, of Slemp and Cressy creeks, and flowing in a general southwesterly direction is joined by the Middle Fork about 6 miles southeast of Abingdon, Va. The stream below this junction and until the junction with the North Fork is still known as the South Fork. Below the latter junction it is known as Holston River.

The headwaters of the South Fork are at an altitude of about 2,800 feet, those of the Middle Fork at an altitude of about 2,900 feet, the elevation at the junction being about 1,800 feet. The altitude at the junction of Slemp and Cressy creeks is about 2,575 feet. The distance between the latter junction and the junction with the Middle Fork is about 29 miles in a straight line, and the average slope of the country about 27 feet to the mile. Following the course of the river, however, this distance is about 36 miles, and the average fall between 21 and 22 feet to the mile.

Although the basin is, broadly speaking, a plateau, it is not to be inferred that it has not some very sharply marked mountain ridges. The axes of these ridges extend in a northeast-southwest direction, approximately parallel to the course of the principal streams, and the buttressing spurs of the Iron and the Stone mountains serrate the southern edge with a series of high and jagged ridges. Away from these, however, the country is composed of a series of low, broad swells and wide, flat valleys, all of the slopes being gentle and covered with grass not unlike the famous blue grass of Kentucky. The soil seems very fertile, and good crops of corn, wheat, oats, and hay are produced.

For convenience in describing this large area, the country has been divided as follows: (1) Area drained by the South Fork below junction with the Middle Fork; (2) area drained by the South Fork above junction with the Middle Fork; and (3) area between the South and Middle forks. The area drained by the Middle Fork is described on pages 69 to 77.

AREA DRAINED BY THE SOUTH FORK BELOW THE JUNCTION WITH THE MIDDLE FORK.

This area lies entirely within the eastern half of Sullivan County, Tenn., and to the north and east of Bluff City, the western limit of

the investigation. Throughout the basin occur many small closed basins or sinks, ranging in size from perhaps 50 feet in diameter to areas covering several acres. In many of them water was seen standing to a depth of several feet. Others bore traces of having recently contained water, while others were well drained. These basins are not indicated on any map of the area, and computations of run-off will be much complicated by them, as the amount of water kept back from the streams is a totally unknown quantity. The country rock is a limestone, much jointed and laminated in places, very massive in others, and these sinks are characteristic of that formation. Ledges of slate are numerous. The limestone is gray to black in color, and strikes to the northeast, the dip being frequently as great as 85 degrees. It is of very good quality, being suitable for quarrying into building stone, and a considerable quantity is used locally, none, however, being quarried for shipment, so far as could be learned. Perhaps the the most important use to which this stone is put is for flux at the various blast furnaces. Small amounts are also burned into lime, which is used in the local building operations or is applied to the land. A small quantity is also used as a road material, but this quantity is very small indeed, for little attention is paid to the roads, which as a rule are poorly graded and ill kept. The soil is in places a red clay impervious to water, but seems for the most part to be a gray, yellow, or brownish loam, and is very fertile.

The country on the south side of the river near Bluff City is preeminently suited to agriculture and to stock raising, being made up of a series of very low and broad ridges and small swells or hills rising from 25 to 30 feet above the level of the valleys between, all forming the surface of a plateau elevated 200 feet or more above the river level. The hillside slopes are gentle, ranging from 5 to 10 degrees, and there are large areas of level land. The general impression of the country when viewed from a distance is that of a plain, but at closer range it is seen to be very gently rolling. By far the greater portion (about 80 per cent) of the land is cleared and either cultivated in corn or wheat or sodded in grass, the areas of each being about equal. The forest growth occurs in small and segregated areas, too small to have much effect on the run-off from the surface. The character of the growth varies, being in some parts almost exclusively pine, while in others and over the larger part of the area oak and chestnut are the predominant trees. Many other varieties, however, are found in abundance, and occasionally the finer cabinet woods, such as walnut, curly maple, and curly birch. As the main stream is approached the country becomes much rougher, the small stream valleys being more deeply carved and the hillside slopes steeper. The descent from the broad upland plateau to the river plain several hundred feet below is very steep.

Ascending the river the uplands for several miles above Bluff City

are similar to those described, except that possibly the proportion of cleared land is slightly less; but it is estimated to be about 75 per cent of the area, and at least half of it is in grass. Throughout this part of its course the river runs in a channel carved through the soft limestone country rock and into the harder and more resistant slates, producing a very rough bed, the slate being much jointed and laminated and projecting in jagged ridges across the course of the stream; but the fall seems well distributed, there being little noticeable concentration at any point.

Going up the river the portion of cleared land seems to gradually decrease, until near the mouth of Weaver Creek it has diminished to one-half or less. This is a consequence of the greatly changed topography, the plateau character of the uplands having been largely lost, sharp and rugged forest-covered hills having taken the place of the small, round, grassy knolls and wide, level bottoms seen farther down the stream. Near the mouth of Weaver Creek the mountains close in on the river, and from that point to and above the mouth of Morrills Creek all of the basin lying to the south of the stream is very rough. There is no arable land along the river, and the hills are wooded to the top.

On the south side of the stream the country draining into the river below the junction with the Middle Fork is composed of the basins of Jacobs Creek and Denton Valley Creek. Near the river the country is more gently rolling than farther downstream, and as a consequence is more largely cleared, but of the whole area drained by Jacobs Creek probably only about 10 per cent is cleared, most of it near the mouth. A short distance up the stream the country becomes broken and rough and is largely in woodland. For about 3 miles above the mouth of Denton Valley Creek a considerable portion—possibly one-third—of the land is cleared, being largely devoted to grazing. The hillside slopes vary from 15 to 30 degrees. These slopes show a great deal of exposed limestone. Above this 3-mile stretch the country rapidly becomes very rough and rugged and is totally forested.

On the north side of the stream the topography differs slightly from that on the south side, consisting entirely of small hills and rounded swells, with a larger proportion of cleared land, ranging from about two-thirds over the lower part of the basin to three-fourths or more near the Virginia line and around Bristol, while over some of the small drainage basins, such as that of Sinking Creek, more properly known as Beidelmans Creek, from 85 to 90 per cent of the land is cleared and under cultivation or in grass or pasture. The same is true of the area drained by Thomas Creek and of the area known as the Holston Valley, the country being almost level and almost entirely grass covered, the soil being for the most part gray and porous, though some areas of red clay were seen. On the north side of the river, near

Bluff City, zinc is found in paying quantities and mines are now being opened. There are numerous deposits of iron ore throughout the area, and the same is said to be true of all the counties bordering the Unaka Mountains. Over the valleys of Spring Creek (the first tributary entering from Virginia), Wolf Creek, and Fifteenmile Creek the general character of the country is the same as that just described, probably more than 75 per cent of the area being cleared, the soil seeming to be porous and very fertile. Hay and wheat are the chief agricultural products, and as elsewhere in the region a great many cattle are raised. Wherever timber occurs it is hard wood, pine being very scarce. Near Ruthton the proportion of forest land is greater than in any part of this area, and much timber is being cut, forming a profitable industry. Lumbering becomes more and more a source of revenue as the river is ascended.

AREA DRAINED BY THE SOUTH FORK ABOVE JUNCTION WITH THE MIDDLE FORK.

This part of the drainage basin lies almost entirely on the south side of the stream—the area between the forks being too small for the formation of streams of appreciable size—and includes large areas of very mountainous country which is densely wooded. From the junction with the Middle Fork to the mouth of the Laurel Fork the basin is narrow, being shut in by the northward extension of the Holston Mountains, and excepting the land immediately bordering the stream the country is rough and rugged, with steep slopes densely forested, the valleys being extremely narrow and containing little if any cleared land, the land that is cleared being confined, so far as could be ascertained, to the narrow strip bordering the river, and therefore constituting a very small part of the whole.

Above the mouth of the Laurel Fork the mountains recede somewhat from the stream, the strip of arable land becomes wider, and cleared areas are to be found in the basins of some of the tributaries, as on Rosenbaums Creek, where the proportion of cleared land is between two-thirds and three-fourths, while of the whole area lying between the river and the road from Damascus to Holstein Mills about one-third is cleared. The area to the south of the road is entirely in forest, and the slopes are steep and rocky, the country rock being still a limestone formation.

Many sawmills are located near the headwaters of some of the small tributaries, and are engaged in cutting the hard-wood timber. There are also one or two mills along the stream, but they are cutting only a few hundred feet each day.

Widner Creek, Rush Creek, Poge Creek, Mill Creek, Grose Creek, and St. Clair Creek, all tributaries from the south, are small streams draining narrow and confined valleys and rough, mountainous, and forest-covered slopes, the small proportion of cleared land in the basin of each being confined to the narrow strip next to the stream, the

country being rather inaccessible, as roads are few. There is much timber, but owing to the roughness and steepness of the mountain slopes it is exceedingly difficult to lumber it, so that up to the present time very little has been cut.

There is one notable exception to the general character of the country along the river, viz, the area known locally as the St. Clair Bottoms, situated on both sides of the South Fork between Holstein Mills and the Washington County line, extending back 1 or 2 miles on each side of the stream and embracing a large area of very beautiful grazing land, a small part only being cultivated in corn and wheat. These bottoms are broad, and from them the uplands rise very gently, the area being practically all cleared. The country rock is a limestone, a small quantity of which is burned for building purposes and to apply to the land.

Above Holstein Mills the mountains close in again and as a consequence the area is more broken and rough. Very little cleared land is to be seen either along the river or away from it until the head of the stream is reached, when the mountains again recede, leaving the broad and fertile area known as the Rye Valley, which extends from a little below Dickey Creek to and above the junction of Slemp and Cressy creeks, and is rimmed about by high and steep mountain slopes. This valley is very broad and gently rolling, and is almost all cleared and in grass. Dickey, Slemp, and Cressy creeks are small streams draining narrow valleys and areas of steep mountain slopes where the proportion of cleared land is small above the limits of the broad valley just described.

AREA BETWEEN THE SOUTH AND MIDDLE FORKS.

This area is a long and narrow strip, 5 or 6 miles in width at the widest part and about 29 miles long, measured from the headwaters of the two streams to the point of junction, and slopes from the crest of the Blue Ridge toward the southwest, the area being about equally divided between the drainage systems of the two forks.

From the junction of the streams to the slopes of the Pond Mountains the country is level or gently rolling, the hillside slopes being slight. The soil is largely a red clay quite impervious to water, though there are large areas of a light-yellow porous soil. The cleared land forms about three-fourths of the area and the wooded portions are too small and as a rule too widely separated to have much effect on the run-off.

South of Marion the large sandstone areas represented by the Pond and the Brushy mountains are all wooded and quite steep. Even where the timber has been cut away the smaller trees and underbrush have grown rapidly and cover the ground with a dense shade. Some of the slopes, however, are composed largely of a species of talus, small angular fragments of the stone comprising the mass of the uplift, covering them in places to a depth of several feet, where the growth is sparse, consisting of small bushes and straggling trees.

RAINFALL.

The annual rainfall over the basin of the South Fork is comparatively large, averaging probably between 40 and 41 inches per annum, diminishing somewhat as the stream is ascended. Over all the basin the summer rainfall seems greater than that of any other season, heavy rain storms being of frequent occurrence, causing large and rapid rises in all of the streams. Severe droughts are relatively infrequent and are soon broken. The drought of the summer and fall of 1900 was said to be the most severe in the history of the region, and it is thought that the low-water gagings made at that time represent the minimum discharges of the streams.

FORESTS.

The forest growth of the basin is mostly oak, chestnut, and pine, with some spruce, walnut, maple, hickory, beech, birch, dogwood, cherry, ash, locust, and poplar, and still smaller quantities of other woods. There are important lumbering industries, notably those near Bristol, although throughout the area numerous mills, large and small, are working up the raw material. In many places large quantities of tan bark are stripped, much of it going to the great tanneries at Bristol. The chief industry of the region, however, is cattle raising, large numbers of which are shipped annually from this section.

MINERALS.

Iron ore is found at a great many points within the basin, and is being mined at some localities, although from some cause the business seems to be languishing, most of the furnaces being out of blast. Zinc is found near Bluff City, Tenn., and gold, barytes, and fluorspar are found in small quantities at various places. There are large deposits of gypsum in the valley of Walker Creek; sandstone, granite, and dolomite occur in small areas; and limestone of excellent quality is found in abundance everywhere. Near Marion, Va., the limestone is quarried in considerable quantities and is shipped to the alkali works at Saltville, Va., where there are extensive saline deposits.

TRANSPORTATION.

The basin is traversed by the lines of the Southern Railway as far as Bristol. The Norfolk and Western Railroad extends from that point the whole length of the basin, and the Bristol and Elizabethton, the East Tennessee and Western North Carolina, the Holston Valley, and the Ohio River and Charleston Railroad afford comparatively good communication with the greater part of the area.

DISCHARGE MEASUREMENTS.

During the investigation many measurements were made of the river and its tributaries, and one gaging station was established in

the basin, viz, at Bluff City, Tenn. The miscellaneous measurements made on the South Fork and also those made at the gaging station are given in the following table. The measurements made on the tributaries are given in the table on page 53.

Discharge measurements of South Fork of Holston River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-ft.*
July 17	Bluff City, Tenn	E. W. Myers and L. V. Branch.	0.25	378
Aug. 16	do	do	0.25	329
Sept. 25	do	do	1.15	791
Nov. 8	do	do	0.90	681
Dec. 27	do	do	0.60	382
July 23	Below mouth of Middle Fork, Va	L. V. Branch	3.06	298
Oct. 3	do	E. W. Myers	3.21	199
July 28	Below mouth of Laurel Fork, Va	do	2.60	652
Oct. 3	do	do	3.39	149
July 28	Above mouth of Laurel Fork, Va	do	1.51	101
Oct. 3	do	do		48
July 27	Rye Valley, Va	do	6.96	30
Oct. 1	do	do		5

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in the above table which were made at Bluff City, Tenn. In making the other measurements given in the table, however, bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In those cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

WATER POWERS.

A water power of considerable magnitude can be developed at Bluff City, Tenn., where the total available fall is between 15 and 20 feet. The only use of the power at present is by the Bluff City mill, a flouring mill having a capacity of 50 barrels per twenty-four hours, using a fall of from 5½ to 6 feet, which with one 35-inch Victor turbine develops about 30 horsepower. Formerly there was a small cotton mill located here which used about 7 feet of the fall, but that is no longer in operation. A development of power could easily be made at this place, the river being narrow, with high bluffs on each side. The railroad facilities also are good.

Above the pond of the Bluff City mill the stream is comparatively placid until just below the mouth of Dry Creek, where there is a shoal having a fall of about 8 feet in 200 yards. The bed of the river is very rough, being crossed by several ledges of rock and containing many loose bowlders. The banks are rather low, being only about 10 feet above low water.

McClellan's mill, the first mill on the river above Bluff City, is on the north bank of the stream about 50 yards above the mouth of Weaver Creek. It is a small combined sawmill, gristmill, and cabinet shop, using a small amount of power, which is obtained from an undershot wheel and a homemade tub wheel, both using a head of about 4 feet, practically all that is available. It is said that curly maple and curly birch are to be found here in considerable quantities, and that other fine cabinet woods abound.

There is one small shoal in the river between McClellan's mill and the mouth of Beidelmans Creek, but the fall is slight and the locality of no practical importance. At the time this stream was first visited, in the latter part of July, 1900, almost all of the small tributaries in this part of its course were practically dry, the largest carrying less than 0.5 second-foot. The stream itself between the points mentioned consists of a succession of still pools, seemingly quite deep, with a very low current velocity broken by short shoals where the depth of the water ranges from a few inches to about 1 foot, flowing over and among water-worn pebbles from 3 to 6 inches in diameter, with occasional rock ledges crossing, where the principal falls are found.

For some distance upstream from the mouth of Thomas Creek the hills on the north side rise rather steeply from the river's edge to a height of several hundred feet, and the valley on the south side is much narrower than those heretofore described. The country rock along the stream is a much jointed and laminated gray or black slate, striking to the northeast and dipping almost vertically. The river flows over the upturned edges of this slate, making a very rough channel, but one in which the fall is well distributed, there being little noticeable concentration at any locality.

About 200 yards below the mouth of Riddle Creek there is a small mill, known as Rosenbaum's mill, which diverts a few second-feet of water from the river by means of a low and loosely piled rock wing dam, a fall of about 5 feet being obtained through a race 150 yards long.

About 1 mile below the mouth of Fishdam Creek and just above the mouth of a small unnamed branch there is a fall of 5 feet in 300 feet, over a rough and rocky bottom, composed of angular bowlders and rock ledges. There are high and rocky bluffs on the north side of the stream, but on the south side the banks rise to a height of about 10 feet, and then a broad meadow slopes gently away. The facilities for building a good dam and a race at this point are excellent.

Just below the mouth of Fishdam Creek is one of the finest mill sites seen on the river. The current is divided by a small island, at the head of which a low loose-rock wing dam has been built, diverting a small part of the current. Another dam has been constructed about 30 yards above the foot of the island, a total fall of 9 feet being thus obtained, which is used by a small sawmill and gristmill requiring probably about 2 horsepower, which is developed by a small flutter wheel. This mill is said to have a capacity of 600 feet of lumber or 40 bushels of corn a day. Power in large quantity could very easily be obtained here, and although at present the locality is somewhat inaccessible, the graded way for the Holston Valley Railroad passes the mill and the track construction work is only a few miles distant.

Fishdam Creek enters the river at the elbow of a great bend known

locally as the Horseshoe Bend. If the river be followed the distance around this bend is about 2 miles, but the distance across the narrow point of the neck is only about 200 yards. This neck is low, being at its highest point only from 40 to 50 feet above river level. From water to water across the neck there is a fall of between 25 and 30 feet, as determined by the aneroid barometer. It is stated that this neck has been leveled over and the difference in elevation in the water surfaces on the two sides determined to be 26 feet. Should it be desired to develop this power, a tunnel or an open canal could be made across the neck and all or a part of the flow easily be turned through it. On the north prong of the bend the river is rather wide, but a low dam could easily be built, and there are large areas of well-protected bottom land, lying well above high-water mark, which would afford ample room for the necessary buildings. The country rock here is a much laminated and jointed slate, not suitable for building purposes.

The next shoal on the river is just above the mouth of Sharp Creek and the Shady Ford. The river here is full of islands large and small, and the fall is heavy, being about 20 feet in a distance of less than a half mile. The water could easily be carried along the southeast bank and used where desired along the river; or by a short extension the race might be carried around a small hill and Sharp Creek be used as a tailrace. The west bank is high and rocky, with numerous bluffs, and large quantities of stone suitable for rough building operations could be obtained from it. Plenty of timber is to be found in the immediate vicinity.

Some distance above this shoal and about a half mile below the mouth of Jacobs Creek there is a shoal having a fall of 6 feet in 200 feet, with a broad bottom on the west side and a high, rocky bluff on the east side. This power, however, is not considered of importance.

From this point to the junction with the Middle Fork the river could not be closely followed, but several localities with falls of between 6 and 7 feet were noted, the first one about 3 miles below the forks. About a half mile above this fall there is a similar shoal, about 1 mile below the forks there is another, while immediately above the forks there is one having a fall of about 8 feet in 100 yards which could easily be developed, as the banks are very high and steep. The bed of the river is in solid limestone and seemingly is very rough, but the stone in the bluffs quarries well, and a considerable quantity has recently been taken out to construct the piers for the bridge of the new railroad from Abingdon to the Shady Valley, which crosses the river at this point.

About a mile above the junction with the Middle Fork is Glenn's mill, a gristmill using about 24 horsepower, which is developed by a 24-inch turbine working under a head of 7 feet. There is a loose rock wing dam which turns a small part of the water behind an island, at the lower end of which a log dam 7½ feet high has been built, from

which a wooden flume 100 feet long carries the water to the mill. There is never any lack of water at this point, and high water interferes with the operation of the mill not more than four or five days in the year on an average.

Above this point there is no noticeable concentration of fall on the South Fork until the mouth of the Laurel Fork is reached, the fall, though large, being well distributed.

About a mile above the mouth of the Laurel Fork is the Rambos mill, a small gristmill using an 8-foot fall and an unknown amount of power, sufficient, however, to operate three sets of stones. The dam is of timber frames planked over and is about 3 feet high and 150 feet long. It turns a small part of the water into a race about 200 yards long. The mill is old and considerably out of repair.

From this point up to about 3 miles below the village of Friendship there are no mills on the South Fork, though several small mill sites were heard of which in the past had been occupied by small gristmills which have been washed away by the floods to which the stream is subject. About 3 miles below Friendship was the best site heard of on this part of the river and the only one visited. This is known as the Buchanan site, and it is stated that there was formerly a very good gristmill here, but nearly all vestiges of it have disappeared. The fall used was about 12 feet, though a much greater fall could be made available by the construction of a suitable dam, which could be made from 40 to 50 feet high without flooding any valuable land.

A short distance above Friendship is Vail's mill, a combined sawmill, gristmill, and planing mill, using 78 horsepower, which is developed by three Success turbines of 24, 27, and 30 inches diameter, respectively, all working under a head of 12 feet. The miller at this mill stated that he had measured the river at its lowest stage and found a flow of 8,000 cubic feet per minute. The dam is of timber frames planked on the upstream side, 12 feet high and 144 feet long, forming a pond 500 yards long. The sawmill has a capacity of 6,000 feet B. M. per day, and the gristmill a capacity of 30 barrels. The year round there is plenty of water to run all of the machinery in this mill at the same time. It is estimated that with a head of 12 feet the river at this point has a flow sufficient to develop 145 net horsepower, and that from this point to the mouth of the Laurel Fork 100 horsepower could be developed every half mile.

About 4 miles above the Vail mill is Love's mill, located just below the Smyth County line. This also is a combined sawmill, gristmill, and planing mill, and is said to use 36 horsepower, developed by a 21-inch Success turbine rated at 20 horsepower when working under a head of 9 feet, and three wooden tub wheels developing a total of about 16 horsepower. The dam is of timber frames planked on the upstream face, and is in fair condition. It is 9 feet high and 150 feet long. It backs the water a distance of three-fourths of a mile, there being little slope in the river above the dam but a considerable fall

just below it. There is no race, a wooden flume 60 feet long carrying the water from the dam to the wheels.

The next mill on the river is the St. Clair roller mill, located about 2 miles below the Holstein mill, at Holstein Mills, in the area known as the St. Clair Bottoms. There is a fall of about 10 feet at this place, and the power used is developed by one 20-inch Success turbine, rated at 20 horsepower; one 35-inch Leffel wheel, Standard pattern, rated at 25 horsepower; and one 20-inch Burnham Brothers' wheel, rated at 20 horsepower; making a total of 65 horsepower when all of the machinery at the mill is in operation. The dam is a timber crib structure planked over on the upstream face, 7 feet high and 100 feet long, backing the water about 500 yards. The race is 200 yards long and gives a fall at the wheels of 10 feet. The mill is rated at 45 barrels per day and has a capacity of between 200 and 300 feet of lumber. At the lowest stages of flow there is not enough water in the river in this part of its course to operate all of the machinery in the mill at the same time.

The next mill on the stream is the Holstein mill, a combined sawmill and gristmill, evidently very old and greatly out of repair, using a fall of 12 feet and an unknown amount of power. This site is a very fine one for a small plant. The dam is of timber frames planked on the upstream face, and is very leaky. It is 12 feet high and nearly 200 feet long. There is no race, a short wooden flume leading the water directly to the wheels, two homemade affairs built on the turbine principle and yielding an unknown amount of power.

About 100 yards below this site is the site of an old woolen mill abandoned about ten years ago. Here there was a 9-foot dam about 150 feet long. At first two small turbines were used, but these required so much water that a race was dug from the dam of the upper mill, and a breast wheel 14 feet in diameter and 9 feet face was installed. This site is said to be one of the best on this part of the stream, suitable for any kind of a mill but particularly adapted for a woolen mill. The mill property includes dwelling houses, school, and church, all in good repair. The mill building has been torn down, however, and any power development would have to be made from the beginning. The valley above this mill is more hilly and is narrower than that below, which, particularly in the part known as the St. Clair Bottoms, is very broad, being 4 miles or more wide and extending back in a gentle rise to the foot of the mountains, with practically all of the land cleared.

Above this there are no mills on the stream until the Rye Valley is reached. In the upper part of that valley there is a small gristmill operating one pair of stones by a large overshot wheel and using a very small amount of power. It is only 5 miles from this mill to the head of the stream, and above it the river is too small to furnish power in appreciable quantities, although throughout the upper part of the stream, from the St. Clair Bottoms to the head of the river, the

fall is very great, the stream being almost one continuous rapid. As determined by the aneroid barometer the fall between the end of the big bend immediately below the Rye Valley and the first ford below—a distance of about 1 mile—is 20 feet; between that point and the mouth of Pomer Creek it is 30 feet; between Pomer Creek and the river surface 2 miles above Holstein Mills it is 140 feet; and between the latter place and the ford below the old woolen mill—a distance of about 2½ miles—it is 150 feet. Through the St. Clair Bottoms the fall is much less, but it is still large, and there are many places where falls of from 10 to 15 feet could be utilized by the construction of dams of suitable height.

TRIBUTARIES OF SOUTH FORK OF HOLSTON RIVER BELOW JUNCTION WITH THE MIDDLE FORK.

DISCHARGE MEASUREMENTS.

During the investigation the drainage basins of all the important tributaries of the South Fork were visited and measurements were made of most of them. The results of the measurements on the tributaries below the junction with the Middle Fork are given in the following table, in order upstream:

Discharge measurements of tributaries of South Fork of Holston River below junction with the Middle Fork.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
Sept. 25	Hatcher Creek	One-half mile above mouth, Tennessee.	E. W. Myers	5.92	0.34
July 20	Sinking Creek	One-half mile above Paperville, Tenn.	L. V. Branch	3.60	3.48
July 29	do	At mouth, Tennessee	E. W. Myers	4.92	11.00
Sept. 25	do	do	do	4.42	9.09
Do.	Thomas Creek	Below railroad bridge, Tennessee.	do		2.46
July 20	Riddle Creek	At mouth, Tennessee	do	12.19	2.00
Sept. 25	do	do	do	11.13	3.00
July 20	Jonah Creek	do	L. V. Branch	11.06	4.00
Sept. 25	do	do	E. W. Myers	11.42	4.00
July 20	Fishdam Creek	do	do	5.25	5.85
Sept. 26	do	do	L. V. Branch	5.26	2.47
July 21	Sharp Creek	do	E. W. Myers	5.36	1.16
Sept. 26	do	do	do	5.33	1.19
July 21	Jacobs Creek	do	L. V. Branch	9.10	2.07
Sept. 27	do	do	E. W. Myers		2.00
July 21	Spring Creek	1 mile above mouth, Virginia	L. V. Branch	0.90	13.00
Sept. 27	do	do	E. W. Myers		10.00
July 21	Wolf Creek	Lower ford of main road up the river, Virginia.	do	2.35	7.00
July 23	do	do	L. V. Branch	2.36	7.00
Sept. 27	do	do	E. W. Myers	2.21	12.24
July 21	Denton Valley Creek.	At mouth, Virginia	L. V. Branch	5.73	6.00
Sept. 27	do	do	E. W. Myers	5.73	4.04
July 23	Fifteenmile Creek.	do	L. V. Branch	4.45	7.37
Sept. 27	do	do	E. W. Myers	4.23	10.46

NOTE.—In making the measurements recorded in the above table, bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

On the following pages are given brief descriptions of the drainage basins and water powers of the principal tributary streams in this portion of the basin of the South Fork, in order upstream.

INDIAN CREEK.

The first tributary investigated was Indian Creek, which enters from the south, near Bluff City, Tenn., and has a total length of about 7 miles, following its windings. The country rock observed over the basin was a slate, brownish-black or gray in color, much laminated and broken, striking N. 70° E., and dipping sharply to the south, from 80 to 85 degrees in some cases. As the mouth of the stream was approached ledges of limestone made their appearance on the tops of the hills.

For the first 2 or 3 miles above the mouth the topography consists of low, rounded hills and broad, flattened swells, cleared to the top for the most part, and under cultivation in grain or grass, the area being about equally divided between those products. The woodland in this part of the basin amounts to only about 10 per cent of the area, but as the stream is ascended the hills are higher and more rugged, with steeper side slopes, and the proportion of cleared land is much smaller, being not more than one-third in the upper part of the basin. Over the lower part of the area the woods are composed almost entirely of hard-wood trees, but near the headwaters these give place to pine.

The fall of the stream is large, being between 450 and 500 feet, averaging between 65 and 70 feet to the mile. Very little of it is utilized, however, but there are three small mills, each using from 10 to 12 feet and operating one pair of stones by means of overshot wheels. Although these three mills use a very small amount of power, at the time the stream was first visited, in July, 1900, it was carrying too little water to operate them. The flow at the mouth was estimated to be about 1 cubic foot per second, though it could not be measured, owing to the shape of the channel. The hillside slopes vary from 15 degrees near the mouth to 50 or 60 degrees near the head of the stream.

In the first 2 or 3 miles above the mouth of the creek traces of three well-defined stream terraces were observed, the upper one being the uplands, the second one a narrow strip of level land lying from 20 to 25 feet above the present level of the stream, following its course but from 100 to 150 yards distant and sloping down very sharply to the level of the present bottom lands, which constitute the third member of the series. The descent in many cases is almost vertical.

Between the mouth of Indian Creek and the Dry Branch, the next tributary upstream, is an old mill known as Worley's mill, not now in operation, which was run by water from a big spring or sunken creek. At the time this stream or spring was visited it was carrying a quantity of water too small to operate the mill, but the discharge was estimated to be approximately 2 second-feet.

DRY CREEK.

Dry Creek, or more properly the Dry Branch, is the next tributary above Indian Creek, and like that stream it enters the river from the south. It has a total length of about 4 miles. The drainage area, which consists almost entirely of gentle swells and small grass-covered slopes or hills, is largely cleared land. At the time the stream was visited it was estimated to be carrying about 0.25 second-foot, the amount being too small to measure.

WEAVER CREEK.

Weaver Creek, the next tributary entering from the south, has a total length of between 5 and 6 miles. The part of the drainage basin lying near the river is very similar to the basins of Indian Creek and the Dry Branch just described, but as the stream is ascended the country becomes rapidly more steep and broken, on account of the rising spurs of the Holston Mountains. It is estimated that two-thirds of the total area drained by this creek is cleared land, the the greater part of it being grass covered. The discharge was estimated to be about 0.5 cubic foot per second, the quantity being too small to admit of measurement with a current meter.

HATCHER CREEK.

The next tributary is Hatcher Creek, locally known as Tow String Creek. At the time of the first visit, in July, this stream was dry, carrying no water for a mile or more above its mouth; but at the time of the second visit, September 25, although the stream discharged no water into the river it was carrying 0.34 second-foot about a half mile above its mouth. This flow, however, sank gradually into the earth within a distance of about 100 yards. The discharge was gaged just above this sink. It seems probable that this stream would begin to discharge water into the river when carrying a small quantity more than at the time of measurement. Its flood discharge is about 4 feet, and like the other streams in the region it rises and falls rapidly.

A great part of its drainage basin is in forest, and the character of the topography is much bolder than that of the areas lying farther to the west, the hills rising higher and the slopes being much steeper.

MORRILLS CREEK.

The next stream entering the river is Morrills Creek, which is about 6 miles long and drains a larger area than any of the foregoing tributaries. Near its mouth the character of the topography is similar to that of the other basins described, but as the stream is ascended the country becomes very rough and broken and the hillside slopes very rough, rocky, and steep. There is much cleared land near the river,

but so far as could be ascertained there is none near the headwaters. Despite its large drainage basin, the amount of water carried by this creek at its mouth at the time it was visited was too small to admit of measurement with a current meter, but it was estimated to be about 1 cubic foot per second.

SINKING CREEK.

The next tributary—the first of importance entering from the north—is Sinking Creek, more properly known as Beidelmans Creek, for Sinking Creek is properly a small tributary of the latter stream. It has a total length of about 12 miles. The upper part of its basin, from Paperville to the head, is broad and flat, consisting of low ridges and flattened swells cultivated to the top, from 85 to 90 per cent of the area being cleared land. From Paperville toward the mouth, however, for about 2 miles the hills close in on the stream, there is considerable fall in the channel, and practically none of the land is cleared, the hillside slopes being too steep and rocky to admit of cultivation. Below this short strip the character of the country is similar to that of the upper part of the basin. The timber, which occurs largely in the 2-mile stretch just noted, is almost all hard wood, and lumbering is an important industry. So far as known there are no mines or minerals in the basin, though large deposits of iron ore are found not far distant.

There are a number of mills on Sinking Creek, all within the 2-mile stretch described, where the stream has cut its way through the Great Knobs, leaving a very rough and steep channel. The first one is about a half mile above the mouth of the creek and is known as Beidelman's mill. It is a small gristmill operating two sets of stones and using a fall of about 8 feet, the power being developed by a 14-inch turbine yielding about 10 horsepower. The dam is of wood, about 2½ feet high and 100 feet long; the race is about 100 yards long, in earth and wooden flume.

Some distance above this and a short distance below the village of Paperville is Nutty's woolen mill, which uses about 14 horsepower, developed by a 14-inch Little Giant double turbine working under a head of 13 feet, which could be increased to 16 feet. This mill operates one set of woolen machinery.

About 200 yards above Nutty's mill is Bruce's mill, which uses a fall of 35 feet on a 12-inch James Davis turbine yielding 12 horsepower and operating one set each of corn and wheat stones as well as sawmill and planing machinery. There is no dam at this mill, the water being turned directly into the race. There is plenty of water except when the mills above close down.

About 200 yards above Bruce's mill is the planing mill operated by J. T. Nutty, where about 14 horsepower is developed by a 13½-inch Burnham turbine working under a 17-foot head, which is used to

operate a full line of sash, door, and blind machinery. The dam is 3½ feet high and 36 feet long, making a pond 200 feet in length. There is at all times plenty of water in the stream to develop this power, and it is stated that the fall could easily be increased to 24 feet.

A short distance above the Nutty planing mill is the sawmill operated by J. H. Maddox, where the fall is 18 feet, about 10 horsepower being developed by a homemade wheel built like a turbine. The plant consists of a small sawmill, including planer, turning lathe, and a pair of corn stones. The dam is 60 feet long and 3½ feet high, backing water to the tailrace of the mill above, a distance of about 100 yards. The race is of wood and is 96 feet long.

One hundred yards above the Maddox mill is the flouring mill of the Farmers' Milling Company, located in the village of Paperville. This is a 40-barrel roller flour mill operated by an 18-foot overshot wheel of 4½ feet face, which is said to furnish 20 horsepower. The flow of the stream at the time of the visit in July was said to be sufficient to operate the mill only about half the time, but for nine months of the year the stream furnishes water sufficient to run the mill night and day. A gaging was made of the water in this flume.

The next mill is about one-fourth of a mile above Paperville and about 2½ miles below Bristol. It is known as the Rutherford mill, and is a gristmill operating one pair of wheat stones. The dam is of wood, 8 feet high, and gives a fall of 11 feet at the mill, through a wooden race about 100 feet long. The power is developed by a 20-inch New American turbine yielding 15 horsepower. It is stated that there is generally sufficient water in the stream to operate this mill all of the time, but when visited in July the flow of the creek was insufficient to operate it more than a very small part of the time. The miller, who had known the stream many years, stated that it was at a lower stage than at any time within his recollection.

The total fall of the creek between Rutherford's mill and Nutty's woolen mill is said to be approximately 135 feet; by aneroid measurement it was determined to be 130 feet. The fall used by the several mills aggregates 121 feet, all within a distance of less than a mile.

THOMAS CREEK.

The next tributary, entering also from the north, is Thomas Creek. Its drainage basin is level to gently rolling, and is from 85 to 90 per cent cleared land, a very large proportion of which is grass covered. At the time of the July visit it was thought that the stream was carrying too little water to be measured with a current meter, but at the time of the September visit the creek was somewhat higher and was gaged a few hundred yards above its mouth. It was carrying 2.46 second-feet. The flood rise is about 5 feet. There is one small combined sawmill and gristmill on the stream, using a small amount of power, developed by an overshot wheel. Formerly there was a mill near the mouth of the creek, but it has been torn down.

RIDDLE AND JONAH CREEKS.

The next two tributaries entering from the south are known as Riddle Creek and Jonah Creek, respectively. These are two small streams of about the same size and having drainage basins of the same general character. Much of the timber has been cut from the area drained by them, and the proportion of cleared and cultivated land is about one-third of the whole. The forest growth, or more properly the undergrowth, on the remainder of the area is very sparse, owing to extensive lumbering operations. It is said that since the lumbering began the streams are much more flashy, falling much lower and rising higher and more rapidly, and that the floods are much more destructive than formerly. These streams attained their minimum stage of flow during the summer and fall of 1900. The average rise at the mouth of each is from 4 to 5 feet. Corn is the principal product of the basin, and no mines or minerals of any kind are known.

FISHDAM CREEK.

The next tributary, which enters the river from the east, at the head of the Horseshoe Bend; is Fishdam Creek. It drains an area entirely forest covered, excepting a few acres at its mouth. The immediate valley is very narrow and swampy and is covered with dense laurel thickets. The hills are steep and at the lower end of the valley are very high and mountainous. The country rock of the basin is slaty in character. The stream seems to have a large low-water flow, and is said to be less flashy than Jonah Creek or Riddle Creek, whose basins have been deforested, but active preparations are now being made to cut the timber in this area also. The Holston Valley Railroad is being graded along its course as rapidly as possible, and after that is completed the timber will rapidly disappear. Fishdam Creek, like all other streams in this section of country, reached its lowest stage during the summer and fall of 1900. During floods the rise at its mouth is about 4 feet above its average water level.

SHARP CREEK.

Sharp Creek also enters the river from the east. It is a small stream draining an inconsiderable area, the largest part of which is in forest, although there is considerable cleared land near the mouth of the stream, where the hillside slopes are gentle, ranging from 10 to 15 degrees. As the stream is ascended the hills are steeper and there is no cleared land. The cleared land in the basin amounts to about one-third of the area. On it fine vegetables and fruits can be grown, grapes thriving especially well. Much of the pine and poplar has been taken out of the forests, but the oak, beech, and chestnut remain. Considerable tan bark has been stripped, but very little has been taken out.

The slopes of the mountain sides are steep, being in some cases 60 degrees or more, and they are often covered with angular fragments of broken stone ranging in size from bits a few inches in diameter to blocks several feet across. The soil of the mountain slopes seems composed entirely of vegetable mold, which is mingled with these fragments. Near the tops of the mountains there is very little rock, the surface being covered with vegetable matter, black and moist, and the forest growth being very dense and luxuriant, composed for the most part of oak, with small quantities of chestnut, hemlock, and spruce. The stream is subject to fluctuations of about 6 feet.

The first mill on the creek is Lawson's mill, a small gristmill operating a single pair of stones by means of a small flutter wheel which yields an unknown amount of power. There is a fall of 14 feet available at this mill, but the quantity of water is very small. Moore & Graham's mill is a small sawmill near the headwaters of the creek. It uses about 14 horsepower and cuts about 500 feet of lumber a day.

Sharp Creek has a large fall and there are many sites where mills could be located.

SPRING CREEK.

The next important tributary is Spring Creek, which enters from the north, a short distance above the boundary line between Virginia and Tennessee. Its drainage basin possesses the same general characteristics as the other basins, consisting of broad, low, and rounded hills and ridges, with wide, flat spaces between, all the slopes being very gentle, and there being from 75 to 90 per cent of cleared land, the larger part of it in grass, hay, and grain, which are the chief agricultural products. In this basin limestone is the country rock and slate is seldom seen. The creek has periods of very low flow, and during floods it rises rapidly to a height of about 5 feet above its low-water level.

The first mill on the stream—Combes & Garrett's—is about a mile above the mouth. It is a gristmill containing two sets of buhrs, two stands of rolls, and a corn mill, the machinery requiring about 10 horsepower for its operation. The power is developed by a 16-foot overshot wheel with 42 inches face, which is said to yield 16 horsepower. The dam is 250 yards above the mill and is of stone, 7 feet high and about 100 feet long. By the use of a turbine 21 feet fall could be obtained at this place.

King's mill, the second mill on the stream, is 2 miles above its mouth. It is a gristmill operating three sets of buhrs driven by a 40-inch Leffel turbine working under a head of 10 feet and yielding an unknown amount of power. It is stated that 8 horsepower is sufficient for the operation of the machinery. The dam, which is at the mill, is of timber frames planked over on the upstream face, and is 10 feet high and 30 feet long, giving a pond 300 yards in length.

Hawkins's mill, the next mill above the King mill, is a sawmill having a capacity of about 2,000 feet a day, using an unascertained amount of power, which is developed by a 36-inch turbine working under a head of 12 feet. There is no race, the dam, which is of stone, 12 feet high and 35 feet long, being located at the mill. It is said that ordinarily there is sufficient water in the stream to operate this mill all of the time, but when it was visited in July the entire flow of the stream was leaking through the dam.

On the top of a hill by the roadside just before Hawkins's mill was reached three or four potholes were noticed which had been worn out in the solid limestone, the country rock over this part of the area. These holes were unmistakably due to the action of water flowing in a stream channel for a considerable period, and as they are more than 100 feet above the present level of the creek they would seem to indicate material changes in this country during very recent geologic times.

JACOBS CREEK.

The next tributary is Jacobs Creek, which flows in from the east and drains a large area of rolling country, slightly broken near the river but very rough and mountainous near the headwaters. The basin is largely wooded, in a very heavy forest growth, and probably less than 10 per cent of the land is cleared. During low water the stream falls to a very low stage, and during floods it rises about 5 feet at the mouth. So far as could be learned neither mineral nor lumber industries are carried on in this basin, nor are its waters used to operate any mills.

WOLF CREEK.

Wolf Creek, entering from the north, is the next tributary. It is about 10 miles long and drains a large area. The valley is wide and flat and is almost entirely cleared and grass covered. Limestone is the country rock, slate being seldom seen, though an occasional ledge of much jointed and laminated slate was noticed. The fall of this stream seems to differ greatly from that of other streams of the region, in that it consists of a succession of vertical plunges of from 1 to 6 feet, the intervening stretches being comparatively still and placid water. Along the upper part of the stream, near Vance's mill, the fall is very great, amounting to more than 50 feet in 1 mile, while above and below that point, where the creek flows through and between the Great Knobs, the fall is much less.

The largest fall on the creek is a few yards above its mouth, and is said to have been measured with an engineer's level and to be about 100 feet in 100 yards; the aneroid barometer, however, gave it somewhat less than that. This fall is the site of the first mill on the stream known as the Falls mill, owned by Pitt & Nutty, of Stump, Va.

Formerly there was a fine mill here, but of late years it has been suffered to fall into disrepair. At the time it was visited in July, however, repairs were in progress, and it was stated that a roller flour mill of 40 barrels' capacity was to be installed at once. The log dam at the head of the falls is 8 feet high and 50 feet long. The race is about 100 feet long and gives a fall at the mill of 36 feet. The power is to be developed by a 12-inch double turbine, which will yield 35 horsepower under the head stated. It is claimed that this site will develop 280 horsepower the year round by using all of the fall, but there is some trouble from lack of water, which at times is held back by the mills upstream until late in the day.

Vance's mill, the next one on the creek, is about 2 miles south of Abingdon, at the upper end of the gorge referred to. It is a small sawmill and gristmill of two runs of stones, the sawmill and each pair of stones being operated by a separate overshot wheel about 16 feet in diameter. No estimate of the amount of power necessary for the operation of the machinery could be obtained. The dam is a timber structure 12 feet high and 100 feet long, and is very leaky. The race is a wooden flume about 150 feet long, giving a fall of 18 feet at the wheels. This power could be greatly increased by taking in a fall of about 6 feet just below the mill and using all of the water in two small turbines.

DENTON VALLEY CREEK.

The next tributary is Denton Valley Creek, one of the largest streams flowing into the South Fork. For the first 3 miles above its mouth there is a large proportion of cleared land in the basin, amounting to probably one-third, practically all of it grazing land. In even the cleared areas the hillside slopes are steep, ranging from 15 to 30 degrees, and show a great deal of exposed rock, everywhere a limestone. Farther upstream, however, the country becomes very rough, rugged, and mountainous, and is densely forested, with a soil that is seemingly very moist all of the time. As the creek is ascended the limestone of the lower part of the basin gives place to a slate, and near the top of the mountains the slate is replaced by a sandstone which on disintegrating becomes a fine, light-yellow to white sand. This stream falls very low and has a maximum rise of 4½ to 5 feet, rising and falling rapidly, although less rapidly than others in the immediate vicinity.

There is but one small mill on the creek, and there is no information concerning it at hand. Near the mouth of the stream are the remains of an old bloomery furnace, seemingly out of operation for many years. As no ore was heard of in the immediate basin it must have been brought from the deposits in the Shady Valley, which can be reached from the head of the stream.

FIFTEENMILE CREEK.

Fifteenmile Creek, entering the river from the north, is the largest tributary. Its drainage basin seems entirely similar, especially as to soil, country rock, and topography, to the area drained by Wolf Creek. The fall occurs in the same succession of plunges and pools as noted on the latter stream, and like it there is at the mouth a very heavy fall in a short distance, in this case amounting to between 135 and 140 feet in about 1 mile. In this part of its course the creek has cut away a deep gorge, and all of the fall could be utilized with a comparatively small expenditure of money. The flow of the stream is ample to furnish a large amount of power from the fall. A short distance back from the stream the country is flat and has the same general characteristics as noted for the limestone areas.

There is but one mill on this stream. It is at the head of the fall mentioned and is known as the Parks mill, being a combined sawmill and gristmill. The latter operates two sets of stones, one for corn and one for wheat, the power for both being furnished by one wheel, a 16-foot overshot wheel of 5-foot face. The old jig sawmill is operated by a small flutter wheel. The dam is a timber-crib structure planked on the upstream side, and is 8 feet high and 50 feet long. The race is short, partly in excavation and partly a wooden flume. It is stated that the stream never falls so low as to make it necessary to use all of the water in the operation of the mill, and according to the best information obtainable it reached its minimum stage of flow during the season of 1900.

TRIBUTARIES OF SOUTH FORK OF HOLSTON RIVER ABOVE JUNCTION WITH THE MIDDLE FORK.

DISCHARGE MEASUREMENTS.

All of the important tributaries of the South Fork below the junction were visited during the investigation, and measurements were made of most of them, the results of which are given in the following table, in order upstream:

Discharge measurements of tributaries of South Fork of Holston River above junction with the Middle Fork.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Second-feet.*
July 28	Beaverdam Creek.	Damascus, Va	E. W. Myers	11.36	18[illegible]
Oct. 3	do	do	do	12.26	32[illegible]
July 29	Whitetop Creek	At mouth, Virginia	do	5.47	10[illegible]
Oct. 2	do	do	do	5.72	34[illegible]
July 29	Atcheson Creek	Near Head of Laurel, Tenn	do	1.82	4[illegible]
Do	Laurel Fork of Holston River.	One-half mile above Laurel Bloomery, Tenn.	do	2.06	23[illegible]
Do	do	Near Laurel Bloomery, Tenn	do	5.12	61[illegible]
July 28	do	One-half mile below Damascus, Va.	L. V. Branch	3.56	351[illegible]
Oct. 3	do	do	E. W. Myers	4.61	88[illegible]

Discharge measurements of tributaries of South Fork of Holston River above junction with the Middle Fork—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
July 28	Rush Creek	Ford 100 yards above mouth, Virginia.	L. V. Branch	3.63	4.20
Oct. 2	do	do	E. W. Myers		2.00
July 27	Mill Creek	One mile above mouth, Virginia.	L. V. Branch	4.32	18.00
Oct. 2	do	do	E. W. Myers	4.43	13.03
July 27	Grose Creek	At mouth, Virginia	L. V. Branch	3.88	2.00
Oct. 2	do	do		(a)	
July 27	St. Clair Creek	do	E. W. Myers	5.76	8.27
Oct. 2	do	do	do	5.94	2.00
July 27	Hogtrough Creek.	Lower ford of main road, Virginia.	do	0.87	9.00
Oct. 2	do	do	do		1.00
July 27	Pomer Creek	At mouth, Virginia	do	2.10	39.00
Oct. 1	do	do	do	2.29	5.00
July 27	Jim Scot Branch	do	do		4.12
Oct. 1	do	do	do		0.50

[a] Almost dry.

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream—the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

On the following pages are given descriptions of the drainage basins and water powers of the principal tributaries of the South Fork above the junction with the Middle Fork, in order upstream.

LAUREL FORK.

The first important tributary of the South Fork above the junction with the Middle Fork is the Laurel Fork, or Laurel Creek, as it is often called, which rises in the northwestern part of Johnson County, Tenn., and flowing in a general northerly and northwesterly direction empties into the South Fork about 4 miles above the junction with the Middle Fork, being joined in its course by two streams as large as itself, viz, Beaverdam and Whitetop creeks. It drains a rough, steep, and mountainous area containing a very small proportion of cleared land, which is confined to the small tracts lying along the stream below Damascus and to the broad meadows about the towns of Head of Laurel and Laurel Bloomery, but these are very inconsiderable in comparison with the total area drained.

Between the mouth of the creek and the first ford there is a fall of about 10 feet, and about 100 yards above this ford there is another fall of from 6 to 7 feet over rock ledges which cross the stream at right angles. Above this the average fall per mile is very large, and though it is well distributed there are a number of places where fine mill powers could be obtained by building dams; and as the banks are high and steep and the slope of the channel is great, no arable land would be flooded. As a rule the banks on the north are precipitous cliffs of limestone from 100 to 150 feet in height, while

on the south side the banks are lower and in places wide bottoms spread out.

There is a fall of about 50 feet between Damascus and the mouth of Whitetop Creek, a distance of about 2 miles. The valley along this stretch is quite narrow and the banks are high, there being only two or three strips of clearing, which lie well above the limits of high water and are of small area, from three-fourths of an acre to 1 acre each. The hills rise steeply from the river, and the opportunities for building high dams are numerous.

Above the mouth of Whitetop Creek the fall of the stream is very great, being between 265 and 270 feet between that point and the first ford below the town of Laurel Bloomery, a distance of about 4½ miles, making the average fall about 60 feet to the mile. Along this portion of its course the stream falls continuously over ledges and bowlders, and there is no stretch of still or smooth water. In places the fall is greatly concentrated. The valley is very narrow, and the hills rise almost perpendicularly from the stream to heights of from 200 to 300 feet. There is much white pine and spruce throughout this section, and there seems to be absolutely no cleared land upstream from the mouth of Whitetop Creek until near Laurel Bloomery. There is only one small tributary stream in this distance, but there are many springs, and the stream gains a large amount of water from them and from seepage between the rock layers. Near Laurel Bloomery the valley widens out and contains much cleared land, practically all of it in grass. The site of the only furnace is about a half mile from the lower end of the valley. No trace of it remains, however, except remnants of the log dam and some heaps of cinders.

Between Laurel Bloomery and the gap or divide separating the waters of the Laurel Fork from those draining into the Watauga, the general appearance of the valley is very like that of the lower part of the Holston Valley, consisting, as it does, of broad, low, and gently rolling swells, almost entirely cleared and grass covered, with herds of cattle feeding over them and with the general appearance of prosperity which marked the other area. The upward slope is gradual, and the whole character of the stream seems in every way different from that of the lower part of its course.

Although power in large amounts could be obtained almost anywhere on the Laurel Fork, very little use has been made of its waters. The first power used is at the mill of A. A. M. Mock, about 1½ miles above the mouth of the stream. This is a combined sawmill, gristmill, roller mill, and flour mill. The buildings are old and greatly in need of repairs. The available fall is 10 feet, and the water is turned onto a 20-horsepower Leffel turbine, used in the operation of the flouring mill and the gristmill, while an old, homemade wheel operates the sawmill. The flour mill has a capacity of 30 barrels per day, the sawmill a capacity of less than 1,000 feet. The dam, which

is of logs, is about 200 yards above the mill and is 4 feet high and 150 feet across the top.

The first power development in the valley, near Laurel Bloomery, is the pipe factory, which uses a small amount developed by a 10-foot overshot wheel with 4 feet face. This factory manufactures pipe stocks from laurel burls. About 200 yards above this is a small gristmill with only one run of stones, using a fall of 10 feet. Above this gristmill there is no utilized power until the mouth of Gentry Creek is reached, where Robinson's mill, a small gristmill of one run of stones, is located, taking water from Gentry Creek and using a fall of about 10 feet and a very small amount of power. A short distance above this mill on Gentry Creek there is a similar mill on the Laurel Fork. As far as the mouth of Atcheson Creek the fall is small and there are no mills, the creek flowing placidly along between wide and fertile bottoms.

Limestone becomes less abundant as the creek is ascended, and much gneiss, quartz rock, and sandstone make their appearance, while occasionally a thin stratum of a species of conglomerate composed of rounded and water-worn pebbles firmly cemented together and lying conformably with the limestone is to be seen.

The Laurel Fork receives two large tributaries and a number of small ones. The first tributary of importance as the stream is ascended is Beaverdam Creek, which enters just below the village of Damascus.

Beaverdam Creek.—This stream rises in the curious elevated valley between the Holston and the Iron mountains which is known and famed throughout the country as the Shady Valley. Throughout the greater part of its length the stream is inaccessible, there being no roads traversing the area, which is very rough, rugged, and mountainous, and is entirely forest covered, except for the small area of cleared land in the Shady Valley. A railroad, however, is now being built along the creek to tap the forests of the Shady Valley, and the country will soon be opened for settlement and for lumbering.

There is only one mill on the stream, and this is located a few yards above its mouth, in the village of Damascus, and is known as Wright's mill. It is a small wood-working shop and corn and chop mill, requiring about 16½ horsepower, which is developed by a 16-inch Little Giant turbine working under a head of 16 feet and using only a very small part of the water carried by the stream. The race is a wooden pipe 1,000 feet long, which follows the level of the stream. The dam is 1 foot high, barely sufficient to turn aside a small part of the water, and of course it gives no pond. At the time the stream was visited in October it was discharging 32.4 second-feet, and was said to be 6 or 8 inches above its extreme low-water mark. The flood rise at this point is about 4 feet.

Indications seem to point to the fact that the Shady Valley was at one time an old lake bed, or at any rate that still water had much

to do with its present formation, since in many places timber is found buried several feet below the surface of the ground. The valley floor is rather level, though seemingly higher in the middle than at the edges. The soil is deep, rich, and moist, being very swampy in places, owing to insufficient drainage. The forest growth is very luxuriant, chiefly white pine and spruce, though some chestnut and other trees are found, some of them of great size, being 100 feet to the first limb. It is stated that the timber in the valley will average 10,000 to 12,000 feet B. M. per acre, and that some tracts will run as high as 50,000 feet per acre. In the swampy areas the soil seems to be entirely a rich, black, vegetable mold, in many places very acid and requiring the application of lime before it can be cultivated with success. In the higher parts of the valley the soil is of a light-yellowish color, with some clay, and fine crops of corn and wheat are produced. The lower part of the valley is more broken and hilly than the upper part, and the proportion of cleared land is much less, diminishing to nothing between 2 and 3 miles below the town of Shady. The Empire Lumber Company is now constructing a large sawmill in this valley. All bricks necessary for their building operations have been burned from a fair quality of brick clay found on the spot.

Whitetop Creek.—This is the next tributary of the Laurel Fork, entering that stream about 2 miles above the mouth of Beaverdam Creek. It drains a very large area, which is entirely forested, the basin being covered with high and rugged mountains having steep and rocky slopes. The fall in the creek is said to be very great and to be much concentrated in places, making wild and picturesque scenery. There are no roads traversing the basin, with the exception of one leading to Whitetop Mountain, so that the country is inaccessible unless the creek be waded. At the time of the July visit the stream was carrying 100 second-feet of water and was said to be 5 or 6 inches above its low-water level. Its extreme flood rise is between 6 and 7 feet. The timber found in the basin includes all of the varieties usually found in the high mountains, and the country rock is reported to be a limestone over the lower part of the area, giving place to metamorphic rocks as the stream is ascended. Some of the higher mountains on the borders of this basin are said to be among the most picturesque in all the mountain region, Whitetop and the views obtainable from it being particularly beautiful. This mountain is a summer resort, being a favorite place for mountain parties. The construction of the railroad up the valleys of the Laurel Fork and Beaverdam Creek will in a measure open the valley of Whitetop Creek also, and will render practicable the development of many of the water powers along its line. This will probably be the result, the power being used in the operation of small flouring mills, which will thus be enabled to find a market for their products, or in woodworking establishments, for which this section offers a very fine field,

as material of the best quality exists in abundance on almost every mountain side. A beginning in this direction has been made by the establishment at Abingdon and at Laurel Bloomery of small mills for working the laurel burls into pipe shapes, from which so-called French briar pipes are manufactured. So far as could be ascertained there are no mining operations in this basin and no minerals occur in profitable quantities.

ROSENBAUMS CREEK.

Rosenbaums Creek, or, more properly, Rosenbaums Branch, is the next tributary of the South Fork. This is a small stream not more than 4 or 5 miles long, draining a narrow valley and discharging a quantity of water too small to be measured with a current meter, but which was estimated to be about 0.5 second-foot at the time of the visit in September. This is, however, not the discharge from the whole area, for as the stream was ascended the channel was found to be perfectly dry less than a mile above the mouth, though the stream was carrying an appreciable quantity of water about 1½ miles above the mouth, the entire flow sinking into the earth. So far as seen the basin consists of rather low hills, grass covered, with very steep slopes, 40 degrees in some cases. The proportion of cleared land is large, being between two-thirds and three-fourths of the area, and is confined to a strip lying along both sides of the creek. Much of the area—probably more than one-half—is in grass, the remainder being about equally divided between corn and wheat. The country rock seems invariably a limestone, and the soil is light and porous. A small amount of timber is being cut on the hills rimming the basin, being worked by a number of small mills on the spot.

WIDNER CREEK.

Widner Creek joins the South Fork about 2 miles above the mouth of Rosenbaums Creek, and though the area drained by it seems to be slightly larger than that drained by the latter creek, and a larger proportion of the basin is said to be forested, the discharge was very much less, being inappreciable at the mouth, the only place where the stream could be seen.

RUSH CREEK.

Rush Creek, the next tributary, enters the South Fork about 2 miles south of the village of Friendship, and is a slightly larger stream than either of the last two described. The area drained is very rough and mountainous, and is about two-thirds forest covered. At the time it was visited, on October 2, it was carrying 2 second-feet, and was said to be at its lowest known stage. Its flood stage is about 3 feet higher.

MILL CREEK.

Mill Creek, the largest and most important tributary entering the South Fork along this part of its course, was gaged about a mile above its mouth, the only place where the stream could be reached, and on July 27 was carrying 18 second-feet and on the 2d of October 13.03 second-feet. The drainage basin is inaccessible and was not visited. Residents of the locality state that with the exception of a narrow strip along the creek not far from the river the basin is very rough, rugged, and steep, and is entirely forest covered. Much less than one-third of the total area is cleared land. There are a number of large springs in the basin. The stream was stated to be at its extreme low-water flow at the time of the October visit, when it was carrying 13.03 second-feet. The average flood rise is about 4 feet, although in some cases it has been as great as 5 and 6 feet.

GROSE CREEK.

Grose Creek is a small branch which was carrying 2 second-feet on July 27, but was almost dry at the time of the October visit. Its drainage basin seems to differ in no way from those of the streams entering below it.

ST. CLAIR CREEK.

St. Clair Creek drains perhaps a larger proportion of cleared land than any other stream in this vicinity, all the land along it being cleared to the foot of the mountains, but probably four-fifths of the entire basin is in forest. This stream was measured near its mouth at time of extreme low water, on October 2, and was carrying 2 second-feet. The rise during floods is about 4 feet.

Considering as a whole the area drained by Widner, Rush, Grose, and St. Clair creeks, it is very rough and mountainous, with steep, forested slopes, the small proportion of arable land, which amounts to less than one-fifth of the area, being confined to narrow strips bordering the creeks and immediately along the river.

WEDSTONE CREEK.

Wedstone Creek enters the river from the south, at Holstein Mills, and at the time it was visited it was carrying a quantity of water too small to even be estimated. Its extreme flood height is about 3 feet above its low-water stage. Its drainage area is largely cleared land, the forested portion being less than that of any of the other basins mentioned and estimated to be about one-third.

HOGTROUGH CREEK.

Hogtrough Creek, the next tributary above, was also too small to measure at the time of the September visit, carrying about 0.5 second-foot (estimated), which is probably the minimum flow. The flow

height is about 3 feet. The area drained is for the most part rough and steep, and the proportion of cleared land is very small, being confined entirely, so far as could be ascertained, to the first 2½ or 3 miles above its mouth and to tracts lying within 200 or 300 yards of the stream.

There are two small mills on the creek, the first one about 100 yards above its mouth, being a small sawmill and gristmill known as Pierce's mill. The power is obtained from a 16-foot overshot wheel with 4 feet face. The mill operates only one pair of stones, grinding for toll only, and saws an extremely small amount of lumber. About a mile above the mouth of the creek is a small mill operating one pair of stones by a 16-foot overshot wheel, but the name of the owner was not ascertained, nor any data regarding the power developed.

POMER CREEK.

Pomer Creek is the largest tributary to the South Fork in this part of its course. It drains an area rougher and steeper than any of those yet described, and one containing a smaller proportion of cleared land. The cleared area is confined to a narrow strip along the stream close to its mouth. There are no mills on the creek, so far as could be ascertained, though about a mile above its mouth there are evidences of a mill, which was probably washed away by one of the freshets to which the stream is subject. This creek reached its minimum flow in the fall of 1900. It was measured on October 1, when the discharge was 5 second-feet. The flood rise is about 4 feet. The amount of water carried during floods is very great.

This was the last tributary investigated, as the river was not followed much above the Rye Valley, and was too small at this point to be of value for water-power purposes. There is but little scenery worthy the name to be found over the larger part of this area, most of the country presenting a very quiet, pastoral type of beauty.

MIDDLE FORK OF HOLSTON RIVER.

PHYSICAL FEATURES.

The Middle Fork rises a little to the south of the village of Old Mount Airy, Va., on the western slope of the Blue Ridge, in the valley between Walker Mountain on the north and the Brushy Mountains on the south, and flows in a direction generally parallel to the course of the South Fork until a few miles above the junction, where it turns to the southwest. Below the junction the stream continues its general southwesterly course, and after being joined by the Watauga it unites with the North Fork of Holston River, near the town of Kingsport, Tenn., forming Holston River, which is in turn joined by the Nolichucky and the French Broad and finally unites its waters with those of the Little Tennessee, forming a system which drains southeastern Virginia, western North Carolina (excepting a small portion the waters from which flow into the New river syste

eastern Tennessee, northern Georgia, and northern Alabama. That part of the area lying in the basin of the South Fork is mapped on the Roan Mountain, Bristol, Abingdon, and Wytheville atlas sheets of the Geological Survey. The area drained by the Middle Fork lies mostly to the north of the river, the distance from the summit of the ridge dividing its watershed from that of the South Fork to the stream being too small to admit of the formation of streams of considerable size. The general character of the country is similar to that of the area drained by the South Fork below the junction, the topography consisting of small and rounded hills and ridges, grass covered to the top, with very gentle slopes and with low divides between the small creek watersheds. By far the larger part of the area is cleared land, the woodland amounting to probably less than 10 per cent for that part of the basin lying between the junction and the mouth of Bear Creek. Above that point the valley becomes very narrow, being constricted between the slopes of the two peaks forming the Brushy Mountains, which are in a large measure wooded. Throughout the remainder of the basin the wooded areas are mostly in the form of small groves or tracts of a few acres. The soil is seemingly very fertile and is light and porous, though some areas of clay were found. Limestone is the country rock, and the bed of the river is also in that stone. The area drained by the Middle Fork constitutes the finest and most prosperous farming and stock-raising country seen during the whole investigation, and the lands are held at a high valuation.

DISCHARGE MEASUREMENTS.

During the investigation a number of measurements were made of the flow of this stream and of its principal tributaries. The measurements made on the Middle Fork are given in the following table, those made on its tributaries are given in the table on page 73.

Discharge measurements of Middle Fork of Holston River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-ft.*
July 25	Sevenmile Ford, Va	L. V. Branch	13.00	[illegible]
Do	Above mouth of Bear Creek, Virginia	do	6.23	[illegible]
Oct. 1	do	do	7.69	[illegible]
July 24	Five miles above mouth, Virginia	E. W. Myers	5.96	[illegible]
Sept. 28	do	do	6.21	[illegible]

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

WATER POWERS.

For 100 yards above the junction with the South Fork there is a fall of about 8 feet in 100 yards, as near as could be ascertained, over a very rough and rocky bed formed by ledges of limestone crossing the

river at right angles. High and steep bluffs rise from the water's edge on both sides of the stream, and from them large quantities of limestone could be quarried. A railroad crosses the stream just below the shoals, and would afford ample transportation facilities. This locality would repay an investigation by anyone desiring power in this section.

About 2½ miles above the mouth of the stream there is a fall known as Big Shoals, where the river is divided by several islands, the largest of which is about an eighth of a mile long. In one-fourth of a mile, as near as could be estimated, there is a fall of 10 feet, determined by hand level and aneroid, and near the head of the shoals there is a fall of about 4 feet in a distance of 100 feet, and an abrupt descent of about 3 feet at the foot over a rock ledge crossing the stream at right angles. On the south side of the river broad bottoms extend the length of the shoals, but on the north side the banks are high and bluffy. The country rock close to the river seems to be slate of two varieties, one hard and black, the other soft and either yellow or gray. Limestone occurs in small quantities close to the stream, but it forms the predominating rock of the uplands.

From the mouth of Hogthief Creek to De Busk's mill the river is a placid stream, with very little fall. The rock is a limestone which quarries well, and almost all of the country, which is very rolling, seems to be cleared. At De Busk's mill there is no race, a wooden flume taking the water from the forebay to the wheels. The dam is a timber structure planked on the upstream face, 10 feet high and 168 feet long, backing the water about 2 miles. The mill is a sawmill, but it also contains wood-working machinery. It is operated by a 36-inch turbine rated at 30 horsepower under 9½ feet head, and has a capacity of 5,000 feet of lumber per day. At this site there is also a wheat mill with a capacity of 30 barrels per day, consisting of three double stands of rolls operated by a 20-inch Success turbine rated at 25 horsepower. The corn and feed mill is operated by a homemade wheel yielding about 4 horsepower. Sometimes during very dry seasons when all of the machinery of the mill is in operation at the same time the whole flow of the stream is required, as the dam is somewhat leaky, and at times the pond has been drawn down 1 foot during a day's run.

Above the De Busk mill and as far up the stream as Chilhowie there is very little fall in the river, and what there is is very well distributed, there being no noticeable concentration at any place. There are localities, however, where dams from 10 to 15 feet high could be built, but in every case the fall obtained would be that due to the dam, and the flooding of valuable lands above would prohibit the construction. The bottoms are very broad and lie only a few feet above the level of the river. The river receives practically no drainage throughout this part of its course, one stream only, Huttons Branch, being large enough to gage. The country rock is a limestone, and the land is practically all cleared and is given over to stock raising and to grain.

Above Chilhowie and as far as Sevenmile Ford there is no concentration of fall in the stream, and the country preserves the same general character, except that the bottoms begin to grow narrower and the hills to close in on the river and to rise higher and more sharply, the country presenting a much more broken appearance. The area is not so largely cleared, there being probably 25 per cent of woodland in this section. The stream has an extreme rise of 12 feet in this part of its course. At present there is no mineral industry hereabouts, though several years ago much baryta was mined, but practically all has been taken out that can be worked at a profit.

Glenn's mill is the first mill on the river above the De Busk mill. It is just above the mouth of Byars Creek, and is a combined gristmill and sawmill having a capacity of 40 barrels of flour per twenty-four hours, and, with three choppers, requiring about 46 horsepower. The total power development here is 64 horsepower. The wheels are homemade, center discharge, built on the turbine plan, and of 20, 16, 10, and 6 horsepower, respectively. The sawmill contains one sash saw requiring for its operation about 12 horsepower. The dam is of timber frames planked over, and is 11½ feet high and 120 feet long, giving a working head of 11 feet at the mill and backing water about three-fourths of a mile. It is stated that there is always sufficient water to operate all of the machinery in this mill at the same time, though the dam is somewhat leaky.

The next power on the stream is about one-fourth of a mile below the town of Marion and is owned by Messrs. Look & Lincoln, who state that a fall of 10 feet can be obtained by building a dam of that height, and that no arable land would be flooded.

Look & Lincoln's mill, the next power above, is in the lower end of the town of Marion. Wagons, plow handles, and wagon materials are manufactured. There are two dams, the upper one of stone for half its length and of wood for the remainder, 9½ feet high and 110 feet long, the water being turned directly into a 33-inch Success turbine developing about 30 horsepower. It is estimated that with this fall from 40 to 45 horsepower can be obtained the year round. Just below this dam the river makes a very abrupt bend, and about 150 yards below the upper dam, if the course of the river be followed, or 40 yards in a straight line, is the lower dam, belonging to the same firm. This dam is 8 feet high and 100 feet long, made of timber frames planked over, and backs the water to the foot of the upper dam. The water is led direct to a 36-inch turbine yielding about 20 horsepower, which is used occasionally to operate two sets of corn stones and a turning lathe. A steam engine of 100 horsepower is also used in the wagon-material department. The whole mill has a capacity of about 300 farm wagons annually and about 2,000 pairs of plow handles.

In the upper end of the town of Marion is Hull & Staley's mill, which has a capacity of 75 barrels of flour per day. The dam is one-fourth of a mile above the mill, and is of timber frames planked over.

It is 12 feet high and gives a head of 20 feet at the mill. There are two turbines, one a 30½-inch Leffel developing 32 horsepower, the other a 24-inch Success wheel developing 18 horsepower, and it is said that in seasons of low water the entire flow of the stream is necessary to operate the larger wheel.

About 3 miles above Marion is the Mount Carmel mill, a flouring mill with a capacity of 50 barrels per day, using about 32 horsepower, which is developed by two 30½-inch Leffel turbines working under a head of 9 feet. There is no race, the mill being built at the dam, which is new, of timber frames planked over, 9 feet high and 125 feet long, backing the water about 400 yards. The miller estimates that in the driest seasons there is in the stream only water sufficient to develop 16 horsepower with this head. He also stated that a portion of the water carried by the stream sinks into its bed between this mill and the town of Marion, but no evidence of this was seen.

There are no other mills or mill sites between the Mount Carmel mill and the mouth of Bear Creek, although the fall is considerable, and from the configuration of the country it seems probable that at a number of localities small amounts of power could be developed. The north side of the river is very steep and bluffy, and on the south side the bottoms are higher above the river level than at any other place along the stream. Considerable limestone has been quarried in this vicinity, the greater part of it going to the alkali works at Saltville, Va.

TRIBUTARIES OF MIDDLE FORK OF HOLSTON RIVER.

DISCHARGE MEASUREMENTS.

During the investigation the following measurements were made of the important tributaries of the Middle Fork:

Discharge measurements of tributaries of Middle Fork of Holston River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
July 24	Hogthief Creek	One-half mile above mouth, Virginia.	L. V. Branch	5.00	5.00
Sept. 29	do	do	E. W. Myers		5.00
Do	Cedar Creek	At mouth, Virginia	do		3.42
Do	Halls Creek	do	do	1.73	17.36
July 23	Huttons Branch	do	L. V. Branch	4.45	5.00
Sept. 29	do	do	E. W. Myers	4.43	5.00
July 25	Walker Creek	50 yards above mouth, Virginia	do	4.90	3.00
Sept. 29	do	do	do	4.89	9.00
July 25	Byars Creek	At mouth, Virginia	L. V. Branch	1.52	4.00
Sept. 29	do	do	E. W. Myers	1.58	2.24
July 25	Hungry Mother Creek.	Ford of main road from Marion, Va.	L. V. Branch	1.18	2.45
Oct. 1	do	do	E. W. Myers	1.17	2.36
July 25	Staleys Creek	Marion, Va	L. V. Branch	9.26	14.32
Do	Bear Creek	At mouth, Virginia	do	6.99	2.01
Oct. 1	do	do	E. W. Myers	6.90	3.00

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

Descriptions of the drainage basins and water powers of these tributary streams are given on the following pages.

HOGTHIEF CREEK.

The first tributary of the Middle Fork of sufficient importance to deserve mention is Hogthief or Sevenmile Creek, which enters the river from the north, at Moab, Va., and has a reported length of about 7 miles, although as measured on the map it is only about 4 miles long. The greater part of its drainage basin is cleared, the woodland amounting to probably not more than 5 per cent of the area. About half of the cleared land is in pasture, the remainder being about equally divided between corn and wheat. The whole basin is either flat or gently rolling, though it contains a few small hills, some of which are wooded to the top, but the hillside slopes are all very gentle. Limestone is the country rock of the area. When the stream was visited (first on July 24 and again on September 29) it was, according to all obtainable information, lower than ever before known. On both occasions it was discharging 5 second-feet. It is stated that the maximum rise is about 4 feet. This stream is now much more flashy in nature than it was several years ago, due no doubt to the deforestation of its headwaters which has taken place within the last few years. Not only do the floods rise with greater rapidity and to a greater height than formerly, but during the dry seasons the creek falls to much lower stages, despite the fact that it is fed by many large springs.

The first mill on the stream is Kendrick's mill, located about 100 yards above its mouth. This is a gristmill of two runs of stones, operated by a turbine 12 inches in diameter, which develops 20 horsepower under a head of 27 feet, though it is probable that 10 horsepower will operate all of the machinery in the mill. The dam is about 100 feet above the mill and is about 5 feet high and 25 feet long, built of timber frames planked over, and gives a very small pond. According to the statement of the miller the stream was never too low to run the mill until 1899, but it has been so, except at intervals, since that time, and he attributes it to the cutting away of the timber from the headwaters.

CEDAR CREEK.

The next tributary of the Middle Fork is Cedar Creek, which enters the river from the north, about 3 miles above the mouth of Hogthief Creek, which it seems to resemble in every respect. Practically all of the area drained by Cedar Creek is cleared land, which is used almost exclusively for grazing purposes. The meadows are broad and fertile, and the grass-covered uplands are nearly level. There are a few small hills, but they have very gentle slopes. It is possible that this stream may fall about one-tenth of a foot lower than its stage at the time it was visited (September 29), when it was discharging 3.42 second-feet. Its maximum rise is about 3 feet above its low-water mark.

HALLS CREEK.

Halls Creek, which enters the river a short distance below De Busk's mill, is a slightly larger stream than either Hogthief Creek or Cedar Creek, but the distinguishing characteristics of its drainage basin seem similar in every respect to those noted for the other creeks. It falls between 2 and 3 inches below its level at the time it was visited (September 29), when it was discharging 17.36 second-feet. During floods it rises between 3 and 4 feet.

HUTTONS BRANCH.

The next tributary is Huttons Branch, locally and more properly known as Huttons Creek. This stream rises on the southern slopes of Walker Mountain and drains a very small area of wooded land. The rest of the basin is cleared and is used almost exclusively for grazing, being quite level, with very broad bottoms and small, gentle hills. This stream was visited on July 23 and on September 29, and at both times was carrying 5 second-feet. Its high-water rise is 3 feet. There is one mill on the creek, operating a single pair of stones by means of a 16-foot overshot wheel and using a very small amount of power. The creek forks just below the site of the mill, the forks being at an angle of nearly 180 degrees, and the water from both branches is brought to the mill through a long wooden flume.

CHILHOWIE BRANCH AND CARLOCKS CREEK.

These are the only other streams in this section carrying an appreciable amount of water, and their discharge was much too small to admit of measurement.

WALKER CREEK.

Walker Creek, draining the southern slopes of Walker Mountain, is the next tributary of the Middle Fork. The upper part of its basin is rough and steep and is practically all in woodland, but immediately along the forks there are considerable areas of cleared land, and below them practically all of the basin is cleared. Over this lower part the topography is similar to that noted for the streams lying farther down in the drainage basin of the main stream, except that the hillside slopes are somewhat steeper and the hills a little less rounded. The creek is said to have attained its minimum stage of flow during the summer and fall of 1900. Its flood rise is about 4 feet. There are very valuable and extensive deposits of gypsum in this basin, but they have been very little or not at all worked.

BYARS CREEK.

This creek enters the Middle Fork from the south, about 4 miles below the town of Marion, Va., and is the first important tributary

rising in the area between the Middle and South forks. Considerable of the land in its basin is cleared and under cultivation or in grass. It is rather smooth and level, all of the slopes being gentle. Limestone is the country rock, and it has been quarried in large amounts for use in the alkali works at Saltville. During floods the creek rises about 3 feet at its mouth.

HUNGRY MOTHER CREEK.

The next tributary is Hungry Mother Creek, on the southern slopes of Walker Mountain. The upper part of its basin is a very rough and rugged country of extremely steep slopes, containing a small proportion of cleared land. In the lower part of the basin the country is much more broken than that of the basin of any tributary of the Middle Fork yet described, the hills rising sharply from the stream to considerable heights, and the uplands, which downstream were a plain, consisting of small and rugged hills, seemingly not more than half cleared. In this part of its course the valley of the creek is very narrow. Most of the cleared land is in grass, the remainder being cultivated in wheat; and although much of the area near the mouth is still in woodland, it seems probable that these areas are too small to have very great effect on the run-off. The soil seems shallow, and there is much exposed rock over the basin, all of it seemingly a limestone formation. The floods on this stream are violent, the creek rising 5 feet in a very short time, but the periods of high water are of short duration, owing to the great slope of the stream channel and the steepness of the hillsides over the basin.

STALEYS CREEK.

Staleys Creek, entering the river from the south, within the limits of the town of Marion, Va., is the next tributary. The valley of this stream so far as seen was very largely cleared, probably 50 per cent or more. The lower part of the basin is rolling and grass covered, but the upper part consists of the northern and eastern slopes of the Pond and the Brushy mountains, and is rough, broken, and mountainous, the slopes being very steep and forest covered. The lower part of the basin is in a limestone formation, but the slopes of the mountains are of sandstone. About 4 miles from Marion, in the valley of this stream, is an iron mine owned by Mr. J. L. Woodruff, of Marion, from which about 100 tons of ore are shipped daily to the furnace at Pulaski, Tenn.

The fall of the stream is considerable and it is more largely used for power purposes than any stream of its size in the region. The first fall is known as the Old Foundry site. A fall of 17 feet can be obtained at this place, yielding about 20 horsepower. The site is now unoccupied, but a small wagon factory is to be built at an early date.

About one-fourth of a mile above the Old Foundry site and practically one-fourth of a mile above the mouth of the creek is Seaver's planing mill, where the fall is 18 feet, and it is said that 18 horsepower is developed by one 18-inch Success turbine. The race is a plank flume 1,400 feet long, and there is practically no dam, only a slight obstruction, just sufficient to turn aside the water of the creek. The mill contains wood-working machinery and a gristmill, and it is said that the stream does not at all times furnish power sufficient to develop the horsepower stated, occasionally falling so low as to yield only about 9 horsepower with 18-foot fall.

Atkins Brothers' mill is 4 miles above the Seaver mill and manufactures spokes, hubs, pick handles, etc., and saws walnut timber for export. It uses about 18 horsepower, developed by an 18-inch Success turbine working under a head of 18 feet. There is a very slight dam, barely sufficient to turn the water aside. The water is led to the mill by a plank flume 200 feet long. This is the last mill on the creek.

BEAR CREEK.

Bear Creek, which enters the river from the north about 5 miles above Marion, Va., drains a part of the southern slopes of Walker Mountain and the northern slopes of the Brushy Mountains. The whole area is extremely rough and mountainous. Probably less than one-third of it is cleared land, the cleared areas being confined to the comparatively level land immediately along the stream and to some of the lower and more gentle slopes. The stream probably never falls lower than the point reached during July and August, 1900, when it was carrying about 2 second-feet. During floods it rises about 4 feet at the mouth. Some timber has been cut in the valley, and considerable quantities of tan bark are stripped and hauled to the railroad at Marion. There are no mills on this stream.

WATAUGA RIVER.

PHYSICAL FEATURES.

Watauga River rises on the northern and eastern slopes of Grandfather Mountain, on the southern boundary of Watauga County, N. C., and after flowing about 6 miles in a northeasterly direction is joined by Boone Fork, a stream which rises on the eastern slope of Grandfather Mountain and flows first due east about 4 miles and then to the north about 4 miles, or to its junction with the Watauga. At the junction the river changes its course to the northwest, and with many bends, rapids, and falls flows through Watauga County, N. C., and Johnson and Carter counties, Tenn., uniting its waters with those of the South Fork of Holston River about 9 miles northwest of Johnson City. In its course it is joined by many tributaries. It drains an extensive area, a large part of which lies in the

high mountains. The basin to the west of Carter, Tenn., was not examined, being well out of the mountains and of the same general character as the valley of Holston River already described. For convenience the basin has been divided into three parts, which are differentiated by very well marked physical characteristics. The divisions are: (1) The area lying to the west of the Iron Mountains on the north side of the river; (2) the area lying to the east of the Iron Mountains; and (3) the area lying to the west of the Iron Mountains on the south side of the river.

AREA LYING TO THE WEST OF THE IRON MOUNTAINS ON THE SOUTH SIDE OF THE RIVER.

This portion of the drainage basin of Watauga River comprises the areas drained by Gap Creek, Powder Branch, Buffalo Creek, Sinking Creek, and Brush Creek and is some distance from the mountains. As a consequence it is much less rugged than the country farther to the east, is better adapted to agriculture, and a great part of the land is cleared, hay being the principal product, though much corn and wheat are grown. Most of the area drained by these streams is either level or very gently rolling, and over the greater part of it probably about 90 per cent of the land is cleared, the woodland being confined to the tops of some of the higher hills and to small and isolated areas on the lower but less fertile tracts. Of the total area drained by these streams probably more than 75 per cent is cleared. The soil is deep and fertile and the country rock is without exception a limestone.

One of the peculiar features of this area is the large number of small closed drainage basins, or sinks, which have been noted in other watersheds of the region and which here occur in the nearly level uplands dividing the basins of the various small creeks. These sinks are particularly noticeable for their size and number near Milligan, Tenn., at which place occur the largest seen during the whole investigation, one of them covering an area estimated at 10 acres and having a large pool of water in its bottom. This locality is the only one, however, over the whole area drained by Watauga River in which these basins occur.

AREA LYING TO THE WEST OF THE IRON MOUNTAINS ON THE NORTH SIDE OF THE RIVER.

This portion of the basin includes the valley of Lick Creek, the areas drained by several small branches, the large valley drained by Stony Creek, and a part of the high and rugged area covered by the Holston Mountains. The latter, however, from its character more properly belongs to the area lying to the east of the Iron Mountains.

For perhaps a half mile or a little more to the north of the river, near Carter, the country is very hilly and rough, with steep slopes, and is largely wooded. It changes gradually as the level of the

uplands is reached and becomes gently rolling, being composed of large and broad swells or ridges and low, flattened hills rising from 25 to 30 feet above the level of the valleys between them, the valleys being generally broad areas of level land. The hillside slopes are very gentle, ranging from 5 to 10 degrees. About 75 per cent of the area appears to be cleared, about half of the cleared land being grass covered.

Limestone is the country rock, as on the south side of the river, but very little is seen exposed. The soil is deep and fertile, that in the immediate valleys of the creeks being largely alluvial, while on the uplands it is gray or yellow in color and loose and porous in character.

The forest growth, which is pine, oak, and chestnut, is in small areas, which as a rule are too widely separated to have much effect on the run-off.

The country immediately along the river from Carter to the town of Watauga Valley is much broken by a number of large hills, which are much steeper than those heretofore observed, but just above the latter place these recede from the river, leaving the general appearance of the topography similar to that noted on the south side of the stream, though a little more broken and rough. The hills are the outliers of the Holston Mountains, and are covered with a dense forest growth.

Near Elizabethton the bottom lands are very broad and fertile, extending up the river as far as the mouth of Stony Creek. The valley of the latter stream is of considerable width. Immediately along the creek and on the first bench or terrace the cleared land forms a large portion of the area, but with this exception the basin is in forest. The cleared land is said to amount to from 10 to 12½ per cent of the whole, this being all that is fit for cultivation, on account of the steepness of the slopes, the mountains rising very sharply from the valleys. They all are heavily timbered, little lumbering having been done in this area.

AREA LYING TO THE EAST OF THE IRON MOUNTAINS.

This part of the drainage basin of Watauga River differs very greatly from the areas just described, being rough, rugged, steep, and mountainous, containing a very small proportion of cleared and cultivated or cultivable land, being largely covered with the original forest growth, which is rank, dense, and luxuriant.

As the river is ascended the limestone, which was the country rock over the areas just described, gives place to slates, shales, schists, and sandstones, and these in turn to granites and gneisses, which form the country rocks over all of the basin in North Carolina. Away from the river the land seems to be about one-fourth cleared, but instead of the deep and fertile surface covering seen before the soil is shallow and in many places is full of rock fragments, often angular, sometimes rounded as if waterworn, and in many places a stratum of these

fragments 2 or 3 feet beneath the surface is seen exposed in the banks by the roadsides.

Toward the North Carolina line the amount of cleared land diminishes greatly, the mountains rising too steeply from the water's edge to admit of clearing. As the river is ascended the valley narrows and the mountains rise to greater heights, often showing precipitous walls of bare rock several hundred feet high, forming a chasm known as the gorge of the Watauga. An occasional small clearing may be found on the slopes back from the river, where the country is less rugged, and on these settlers try to wring a scanty subsistence from the stony soil; but as a rule the mountains are forested to the top, though occasionally an undue amount of exposed rock on the slopes renders the growth sparse and stunted.

Within the gorge of the Watauga there is no room for a road and barely space enough for the stream. The channel is very rough and broken by many rapids and sudden falls, and the water rushes along with great velocity. In the 8 miles through which the gorge may be said to extend the average fall is about 65 feet to the mile, and in many places it is much more concentrated, one notable locality being near the State line, where there is a straight plunge of 10 or 12 feet, known as the Falls of the Watauga.

Upstream from the gorge the mountains rise to less heights, the valley broadens slightly, and the uplands back from the river are suitable for agriculture on a small scale. They are partially cleared and cultivated in grass or grain in the places where the hillside slopes are not greater than 20 or 30 degrees. The hills do not recede far enough to permit the formation of bottoms until the broad strip of level land known as Valle Cruces is reached. A short distance above this the gorge is redeveloped, though in a lesser degree, and there is very little cleared land directly along the river until Shulls Mill is reached. There are small areas of cleared land up some of the tributaries, however, also along the river between Shulls Mill and Foscoe, so that it is estimated that of the total area drained by the river above the North Carolina line about one-third is cleared land; but after an inspection of the basin this estimate seems too great. Above Shulls Mill the Watauga has a length of from 5 to 6 miles, measured in a straight line, and drains an area of which a large part is well suited to agriculture, being in the form of broad and fertile bottoms and terrace lands lying close to the stream. About 4 miles above the mouth of the Boone Fork, however, the slopes of Grandfather Mountain on the north and of Hanging Rock on the south close in on the river and the amount of arable land becomes very small, the cleared land being about one-fourth or one-fifth of the whole area above the junction of the Boone Fork. The soil of the bottoms is deep and fertile, being largely a black alluvium, but that of the hillsides is often shallow and full of angular fragments of broken stone, and is not very productive.

The portion of the basin in North Carolina lies in Watauga County, which occupies the entire breadth of the very elevated mountain plateau between the Blue Ridge and the Unaka mountains. It is traversed in a northerly direction by two massive cross chains connecting these two great ranges, viz, the Rich Mountains and the chain of which Grandfather Mountain may be taken as the starting point and Hanging Rock and the Beech Mountains as the prominent peaks, the basin of the Watauga lying to the west of the Rich Mountains. The surface of the whole country is very rough and rugged and has an average elevation of about 5,000 feet above sea level. The stream valleys are as a rule very narrow, but at intervals there are considerable stretches of bottom lands. The soil is generally a stiff gray or yellow loam, producing grains and grasses in abundance. Cattle raising is an important industry. Along the headwaters of the stream there is much alluvial soil in the creek bottoms and a great deal of vegetable mold on the mountain slopes, while on Banner Elk Creek and Elk Creek the bottoms assume the form of peaty bogs, which are very deep and retain the water draining into them from the mountain slopes for a long time, feeding it out to the streams gradually.

SCENERY.

All of the area drained by the Watauga in North Carolina lies in the high mountains, and the scenery is wild and picturesque, the exact opposite of that along the lower part of the stream or on the Holston, which is quiet and pastoral. Many beautiful mountain views are to be obtained, with quick-changing cloud shadows and with wisps of filmy clouds clinging about the summits, but the valleys are so narrow and so tortuous that it is seldom a view can be obtained from a sufficient distance to give its full beauty, although there are places near the gaps and on the divides where may be seen views approaching in grandeur any that the mountains afford.

The rugged beauty of the whole area finds its culmination in the massive bulk of Grandfather Mountain, which rises to a height of 5,964 feet, far above any peak in the vicinity, and is probably the most massive, wild, and rugged of the peaks of the Southern Appalachians. Though by no means the highest peak in the range, it so towers above its surroundings that one of the most extensive views in North Carolina can be obtained from its summit. From certain directions and in clear weather the summit of this mountain is seen to form the profile of an old man—hence the name—but this is seldom visible, for this grandfather of mountains keeps his face almost perpetually veiled in the clouds.

RAINFALL.

Like all other drainage basins throughout this region, the basin of the Watauga is subject to a very heavy annual rainfall, being greater

near the headwaters, where Grandfather Mountain causes an almost constant precipitation. This rainfall at times comes in the form of violent rain storms, but these are infrequent, the precipitation being well distributed throughout the year, though the summer rainfall is the greatest in amount. At times the heavy rains are long continued, lasting a week or more, and the streams rise to great heights and do a vast amount of damage. It is said that the greatest flood known in this section of the country occurred in 1867, when there was a week of heavy rainfall, followed by a violent rain storm lasting twenty-four hours and seemingly extending over the whole basin. At Butler the river rose 18 feet above its low-water mark, washing away several houses and barns and totally destroying a great many acres of valuable bottom lands lying immediately along the river. Similar floods are reported to have occurred in the valley of Roan Creek in 1861 and in 1870. Droughts are infrequent, and as a rule are neither severe nor long continued, the drought of 1900 being the most severe within the memory of the inhabitants of the basin.

SPRINGS.

A marked feature of the region is the great number of springs, the discharge of which ranges from less than a gallon a minute up, several being of very large size. One of the larger springs is in the village of Allentown, Tenn. The spring basin is nearly 100 feet in diameter and has a discharge estimated at from 8 to 10 cubic feet per second. Another large spring is directly on the bank of the river, at the town of Fishspring. Here there are a number of small streams flowing from crevices in the rock, the aggregate volume being 7 or 8 cubic feet per second. The peculiar feature with reference to this spring—for which it and the town were named—is that in the autumn, when the water of the river begins to grow cold, a large number of fish, especially sun perch, come from the river and enter the basin of the larger spring—a cavern beneath the surface of the earth—where they spend the winter, returning to the river after spring opens and the river water is again warm. Twenty-one hundred fish were caught in one season by means of a trap placed at the mouth of this spring when the fish were returning to the river, and 165 have been caught in a single night, all being very fat. This indicates the existence of a body of water of considerable size beneath the surface of the earth. This supposition is borne out by the fact that about 40 feet from the river an area probably 25 feet square has sunk several feet within the last few years, and a hole has opened in about the center of the depression through which fish can in the winter be caught by means of a hook and line.

TIMBER.

There is a great deal of valuable timber still standing in the basin of the Watauga, only about one-third of the area being cleared and in

cultivation. The character of the timber varies as the stream is ascended, hard wood seeming the predominant growth along the lower part of the stream and its tributaries, but gradually giving place to pine, spruce, or hemlock. On the upper part of Laurel Creek and of the main stream, upon which the most extensive timbering operations have been carried on, the growth seems composed entirely of the latter trees, and the yield of timber is heavy. Evidences of extensive timbering are to be seen over almost the entire basin, the river at the time of both visits—one in the summer and the other in the fall—being full of logs waiting for a rise in the stream to carry them down to the mills. Numerous splash dams have been built on the tributaries and several on the river itself.

MINERALS.

Not many minerals or mineral localities are reported from this basin, the only place where mining rises to the dignity of an industry being at the famous iron mines at Cranberry, N. C., where is mined an iron which rivals in quality and purity the best Swedish ore. There are other deposits of iron ore in the basin, those on the upper part of Roan Creek and on Doe Mountain being perhaps the most noted. Formerly some copper was mined at Elk Knob, just beyond the eastern limits of the basin, but nothing has been done there for several years.

TRANSPORTATION.

The transportation facilities for the greater part of the basin are entirely inadequate. The East Tennessee and Western North Carolina Railroad, from Johnson City, Tenn., to Cranberry, N. C., furnishes an outlet for the products of that part of the basin, and the Virginia and Southwestern Railroad, from Bristol to Elizabethton and thence up Watauga River and Roan Creek, serves the northern part of the basin, but the whole area within North Carolina possesses no railroad, its facilities for transportation being limited to the country roads, which with the exception of the one paralleling the river are very poor, being steep, rough, and full of stones, so that it is impossible for a team to haul more than half a load over them. It is thought, however, that this condition will soon be bettered by the construction of a railroad from Lenoir, N. C., to Blowing Rock, and thence across the basin, probably following the course of the river a considerable distance and connecting with other roads, either at Cranberry, Butler, or Mountain City. Watauga County has recently authorized a bond issue of $100,000 to aid in the construction of this road.

DISCHARGE MEASUREMENTS.

During the investigation a gaging station was established on Watauga River at Butler, Tenn., and on two of its tributaries—

Roan Creek at Butler, Tenn., and Elk Creek at Lineback, Tenn. The results of measurements at these stations, as well as of the numerous miscellaneous measurements on the river and its tributaries, are given herein; those made on the main river in the following table, and those on the tributaries in the table on page 85.

Discharge measurements of Watauga River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-ft.*
July 16	Elizabethton, Tenn	E. W. Myers	15.87	450
Aug. 2	do	L. V. Branch	15.77	593
Aug. 16	do	do	16.03	403
Oct. 5	do	E. W. Myers	16.03	348
Nov. 7	do	L. V. Branch	15.27	993
Dec. 28	do	E. W. Myers	15.68	533
Dec. 31	do	Ernest Graves	15.22	973
July 30	Butler, Tenn	E. W. Myers	1.37	434
Aug. 7	do	L. V. Branch	0.90	214
Aug. 17	do	do	0.84	166
Oct. 6	do	E. W. Myers	1.12	228
Nov. 7	do	L. V. Branch	2.20	591
Dec. 28	do	E. W. Myers	1.40	311
July 16	Watauga Falls, N. C	N. C. Curtis		79
Aug. 10	do	L. V. Branch	6.62	53
Oct. 7	do	E. W. Myers	6.52	60
Aug. 11	One mile above Shulls Mill, North Carolina.	L. V. Branch	4.05	19
Oct. 7	do	E. W. Myers	3.78	23

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in the above table which were made at Butler, Tenn. In making the other measurements in the table, however, bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In those cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

WATER POWERS.

The fall of the Watauga River is very great throughout its length, and the selection of shoals for utilization would be largely a matter of convenience, the average fall of the stream in Tennessee being about 15 feet to the mile, and between Shulls Mill and the Tennessee line about 47 feet to the mile, with many short stretches where the fall is much greater. Very little of the vast power in this basin is utilized, however, either on the river or on its tributaries, there being, so far as could be ascertained, only three mills on the main stream, and these all small ones. The first mill is at Watauga Falls. It is a roller flour mill with a capacity of 30 barrels per twenty-four hours. The second one is just below the mouth of Cove Creek, where there is a fall of about 9 feet and a very good location for the construction of dams and buildings. Here there is a small sawmill and wagon shop which uses a small proportion of the water by means of a homemade tub wheel yielding an unknown amount of power.

The first shoal that could be developed into a power of considerable magnitude is just above the North Carolina line, where there is a fall of about 10½ feet, but it is in a deep gorge and at present is so inaccessible that it is of no importance as a power site.

For about 4 miles above this place, or as far as the mouth of Beech Creek, the concentration of fall is very great, and dams of almost any desired height could be built without excessive lengths across the top, and powers could be obtained limited only by the heights of the dams. There is a similar locality just below the mouth of the lower Laurel Creek.

Above this point and on through Valle Cruces there are a number of shoals in the river, but the average fall in the stream is less than that above or below, and since the bottoms are very broad and lie only a few feet above the water level, power could not advantageously be obtained in this part of the course of the river, on account of the flooding of valuable farming lands.

As has been stated, the gorge is redeveloped on a smaller scale a short distance above Valle Cruces, and the slope of the stream becomes very great, being a succession of rapids with large fall and many abrupt plunges. There are a number of places where a dam from 60 to 70 feet high could be built with stone quarried on the spot, while the level tops of the hills would afford a safe and excellent location for buildings; but until this country has made material advances and has provided means of transportation for raw materials and finished products, it is extremely improbable that any development of water power will be made beyond small amounts for purely local needs.

TRIBUTARIES OF WATAUGA RIVER.

DISCHARGE MEASUREMENTS.

During the investigation the following measurements were made of the tributaries of Watauga River, in order upstream:

Discharge measurements of tributaries of Watauga River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
July 19	Brush Creek	Near Carter, Tenn	L. V. Branch	6.77	10.03
Aug. 16	do	do	do	6.82	9.47
Sept. 24	do	do	E. W. Myers	6.94	5.14
Aug. 2	Sinking Creek	Lower ford of Johnson City-Elizabethton road, Tennessee.	L. V. Branch	3.73	5.0
Oct. 4	do	do	E. W. Myers	3.75	4.0
Aug. 2	Buffalo Creek	At mouth, Tennessee	L. V. Branch	5.85	20.0
Oct. 4	do	do	E. W. Myers	5.92	10.0
Aug. 2	Gap Creek	do	L. V. Branch	4.00	7.0
Oct. 4	do	do	E. W. Myers	4.12	3.0
Aug. 3	Laurel Fork of Doe River.	Allentown, Tenn	L. V. Branch	5.19	30.0
Aug. 17	do	do	do	5.50	15.0
Oct. 5	do	do	E. W. Myers	5.67	9.0
Dec. 29	do	do	do	5.05	27.0
Aug. 3	Little Doe River	do	L. V. Branch	4.42	35.0
Oct. 5	do	do	E. W. Myers	4.78	17.0
Dec. 29	do	do	do	4.30	28.3
Aug. 3	Wilson Creek	One mile above mouth, Tennessee	L. V. Branch	3.67	5.0
Do	Shell Creek	At mouth, Tennessee	do	2.35	14.0
Do	Doe River	Two miles below Roan Mountain, Tennessee.	do	8.46	41.3
Do	do	Near Allentown, Tenn	do	5.56	72.0
Aug. 18	do	do	do	5.81	50.0
Oct. 5	do	do	E. W. Myers	5.85	39.3
Aug. 2	do	Above Elizabethton, Tenn	L. V. Branch	5.94	143.4
Aug. 17	do	do	do	6.20	106.0

Discharge measurements of tributaries of Watauga River—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
Oct. 5	Doe River	Above Elizabethton, Tenn	E. W. Myers	6.23	82.0
Dec. 31	do	do	Ernest Graves	5.23	304.0
Aug. 3	Stony Creek	One-half mile above mouth, Tennessee.	L. V. Branch	6.95	44.0
Oct. 5	do	do	E. W. Myers	7.59	16.0
Dec. 31	do	do	Ernest Graves	4.60	48.0
Aug. 13	Doe Creek	Ivyspring post-office, Tenn	L. V. Branch	5.94	9.0
July 30	do	Mouth of Doe (town), Tenn	E. W. Myers	5.23	59.0
Aug. 13	do	do	L. V. Branch	5.49	26.2
Oct. 9	do	do	E. W. Myers	5.46	28.38
July 30	Mill Creek	At mouth, Tennessee	do	9.48	13.0
July 29	Town Creek	At Shoun Crossroads, Tenn	L. V. Branch	3.48	29.2
Aug. 13	do	do	do	3.82	6.0
Do	Forge Creek	Near mouth, Tennessee	do	4.53	7.0
July 30	Roan Creek	Butler, Tenn	E. W. Myers	1.47	137.0
Aug. 7	do	do	do	1.02	65.0
Aug. 17	do	do	do	0.85	58.0
Oct. 6	do	do	do	0.86	52.0
Nov. 7	do	do	do	1.50	171.0
Dec. 28	do	do	do	1.20	82.0
Aug. 13	do	Key Station, Tenn	L. V. Branch	4.85	5.2
July 30	do	Above mouth of Mill Creek, Tennessee.	E. W. Myers	5.70	60.3
Aug. 6	Dark Ridge Creek.	One-half mile above mouth, Tennessee.	L. V. Branch	4.65	3.0
Do	Little Elk Creek	At mouth, North Carolina	do	1.20	6.0
Aug. 4	Blevins Creek	Cranberry, N. C	do	6.03	5.05
Do	Cranberry Creek	do	do	6.95	5.09
Aug. 12	North Fork of Elk Creek.	At Banners Elk, North Carolina	do	5.61	7.0
Oct. 8	do	do	E. W. Myers	5.64	4.0
Aug. 11	South Fork of Elk Creek.	do	L. V. Branch	11.96	9.38
Oct. 8	do	do	E. W. Myers	11.82	8.48
Aug. 9	Elk Creek	Lineback, Tenn	do	3.5	70.0
Aug. 17	do	do	do	3.5	56.0
Oct. 6	do	do	do	3.5	53.0
Aug. 6	do	One-half mile below mouth of the Little Elk, Tennessee.	L. V. Branch	7.21	64.0
Aug. 9	Big Dry Run	One-eighth mile above mouth, North Carolina.	do	1.55	0.85
Do	Fogey Creek	At mouth, North Carolina	do	2.94	1.4
Oct. 6	do	do	E. W. Myers	3.02	2.4
Aug. 9	Beech Creek	Above mouth of Fogey Creek, North Carolina.	L. V. Branch	5.6	7.3
Oct. 6	do	do	E. W. Myers	5.7	7.4
Aug. 9	Beaverdam Creek.	Near Leander, N. C	L. V. Branch	5.59	7.0
Oct. 6	do	do	E. W. Myers		8.0
Aug. 10	Laurel Creek (lower).	At mouth, North Carolina	L. V. Branch	10.62	4.0
Oct. 7	do	do	E. W. Myers		3.0
Aug. 12	Rockhouse Creek	do	L. V. Branch	2.17	16.[illegible]
Oct. 18	do	do	E. W. Myers		0.[illegible]
Aug. 12	Brushy Fork of Cove Creek.	do	L. V. Branch	2.06	5.[illegible]
Do	Cove Creek	Above mouth of Brushy Fork, North Carolina.	do	4.31	23.0
Aug. 10	do	At mouth, North Carolina	do	5.24	12.0
Oct. 7	do	do	E. W. Myers	5.15	14.0
Aug. 10	Dutch Creek	Valle Cruces, N. C	L. V. Branch	7.42	11.[illegible]
Oct. 7	do	do	E. W. Myers	7.37	[illegible]
Aug. 10	Laurel Creek (upper).	At mouth, North Carolina	L. V. Branch	2.62	[illegible]
Oct. 7	do	do	E. W. Myers	2.87	[illegible]
Aug. 11	Moody Mill Creek.	do	L. V. Branch	3.20	4.[illegible]
Aug. 10	Boone Fork of Watauga River	Shulls Mill, N. C	do	2.30	12.0
Oct. 7	do	do	E. W. Myers	2.11	12

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in the above table which were made of Roan Creek at Butler, Tenn., and of Elk Creek at Lineback, Tenn. In making the other measurements in the table, however, bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In those cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

BRUSH CREEK.

The first tributary of the Watauga which was made the subject of investigation was Brush Creek, which rises near Johnson City, Tenn., and flowing in a general northwesterly direction joins the Watauga a short distance below Carter, Tenn., having a total length of between 7 and 8 miles and draining an extensive area. The drainage basin consists of large but low hills with very gentle slopes, largely grass covered. Probably 90 per cent of the area is cleared land, largely in pasture, but a small part is cultivated in corn and wheat. The soil is deep and fertile. The country rock is a limestone.

The creek has a fall of about 400 feet between Johnson City and its mouth. The water is used by two small mills, too small to be of importance, and there is no definite information concerning them at hand. It is probable that this creek reached its minimum stage in September, 1900, when it was discharging about 5 second-feet. During floods it rises about 3 feet above low-water mark at its mouth.

SINKING CREEK.

The upper or second Sinking Creek, which enters from the south, is the next tributary. It drains a narrow area between 10 and 11 miles long, about three-fourths of the lower part of which is cleared. Its headwaters drain the northwestern slopes of the Buffalo and the Cherokee mountains, a rough and rugged area, densely forested. The characteristics of soil and topography over the lower part of the basin are in every way similar to those of the basin of Brush Creek. The stream was very low at the time it was visited, early in October, attaining its lowest stage during that month. It was carrying 4 second-feet when measured on October 4. During floods it rises about 2 feet.

BUFFALO CREEK.

Buffalo Creek, the next tributary, drains a much larger area than either Brush Creek or Sinking Creek. The greater part of its drainage basin consists of low, flat, and rounded hills, for the most part grass covered. Probably from 85 to 90 per cent of the lower portion of the basin is cleared; but as the stream is ascended the country becomes more rugged, being very steep and mountainous near the headwaters, and is largely covered with forest, though it is probable that three-fourths of the entire area drained by the stream is cleared. It is in the basin of this stream that the great number of sinks which have heretofore been mentioned as occurring near Milligan are to be found. These sinks occur from Milligan to the east and southeast as far as Gap Creek. At the time of the fall visit (October 4, 1900) the stream had reached its lowest stage of flow (10 second-feet). Its maximum flood rise is about 3 feet.

Buffalo Creek has three small tributaries—Dry Creek, Toll Creek, and Powder Branch—all of which enter from the southeast.

GAP CREEK.

Gap Creek, the next tributary entering the Watauga from the south, has a drainage basin which seems in every way similar to that of Buffalo Creek, with the exception that no sinks were seen. This stream reached its minimum stage in the fall of 1900. When measured on October 4 it was discharging 3 second-feet. Its flood rise is about 3 feet at the mouth.

DOE RIVER.

The most important tributary received by Watauga River is Doe River, which rises in the high and mountainous area to the west and north of Roan High Knob, and flows in a general northerly and northwesterly direction, joining the Watauga at Elizabethton, Tenn. Near the mouth of the stream probably one-forth or more of the valley is cleared land, the cleared areas being the level bottom or terrace land immediately along the river; but about 2 miles above Elizabethton the gorge of the Doe begins, and from that point to Allentown the river flows in a very narrow channel carved out by its waters from the solid rock, which rises on either side in precipitous walls several hundred feet high. Near Allentown, where Doe River is joined by the Laurel Fork and Little Doe River, there is a considerable area of open and level arable land rimmed about by high and steep mountains. Above that place the gorge of the Doe becomes more pronounced, the sides rising higher and more steeply above the water, and the scenery, though confined, is very much grander than that of the lower gorge. A view in the upper gorge is shown in Pl. XXIII. Throughout the gorge the fall averages nearly or quite 100 feet to the mile, the greater part of it being in rapids; sudden plunges are rare. Power in large amounts could be obtained here. Above the gorge the fall averages about half as much, being about 50 feet to the mile.

The water power of Doe River is used at only two places. At Elizabethton water is taken from the stream above the town and is used in the operation of a small cotton mill and several small gristmills. A small woolen mill is also sometimes operated by power derived from the stream. The largest consumer of power was a woolen mill which was burned several years ago and has not been rebuilt. Near Roan Mountain Station there is a small lumber mill using three turbines working under a head of 12 feet, but the amount of power developed could not be ascertained.

Little Doe River.—This stream, which is tributary to Doe River at Allentown, drains an area in all respects similar to that drained by the main stream above the junction, being very mountainous and largely forest covered. So far as could be ascertained there is prac-

DOE RIVER VALLEY, TENNESSEE.

tically no cleared land above 2 miles from its mouth. None of the power of the river is utilized. The time of minimum flow was in September, 1900. The flood rise at the mouth is about 4 feet.

Laurel Fork.—The next important tributary of Doe River is the Laurel Fork, which joins it at Allentown, draining an area similar to that drained by the main stream and by the Little Doe. The Laurel Fork has a large fall and carries a considerable quantity of water, which is used at Allentown by a small sawmill, and just above that place by a combined sawmill and gristmill using a small amount of power and a fall of 16 feet. Another mill is reported farther upstream. It is stated that active lumbering operations are now in progress over the basin of the Laurel Fork and that much timber has been cut.

STONY CREEK.

The next tributary of the Watauga is Stony Creek, which enters the river from the northeast and drains a long and broad valley containing a larger proportion of cleared and cultivated land than either of the streams just described. The cleared land, however, is confined to the level bottoms bordering the creek and to the first bench or terrace—this being all that is susceptible of cultivation, so it is said—and amounts to only about one-eighth of the whole, the remainder of the basin being steep, rugged, and forest covered. At the time of the October visit the stream was said to have reached a point lower than ever before known. It was then carrying 16 second-feet. The high-water mark is about 6 feet above its level at that time.

The average fall of the stream is large, and its waters are used by several mills, all small, the first one being located close to the mouth of the creek and using a fall of 10 feet, the power developed being estimated at about 12 horsepower. The second mill is a short distance above and is a small corn mill operated by a homemade wheel developing an unknown amount of power. The third mill is about a mile above the mouth of the stream and is a small combined sawmill and gristmill using a small amount of power.

ROAN CREEK.

There is no other important tributary of the Watauga until Roan Creek is reached. The watershed of this stream, which joins the river at Butler, Tenn., is in the area between the Stone Mountains on the north and Snake Mountain on the south. The main stream rises near Snake Mountain and flows in a general northerly direction for 7 or 8 miles, when it is joined by Forge and Town creeks—streams which rise in the Stone Mountains and flow to the south—and turns to the southwest, flowing in that direction until its junction with the Watauga. In the latter portion of its course it receives one large tributary, Doe Creek. Roan Creek drains a very large area, known as Johnson County Cove, which has already been somewhat briefly

described (p. 38). The immediate valley of the creek contains practically all of the cleared land in its basin, though small areas have been cleared on some of its minor tributaries where the land is sufficiently level for cultivation. All of the timbered area is still in luxuriant forest growth, consisting principally of oak and chestnut, though maple, locust, pine, spruce, hemlock, poplar, and similar trees are found. Probably 75 per cent of the area is still wooded. Near the mouth of the stream the valley is very narrow and the proportion of cleared land seems smaller than farther toward the headwaters, where the basin bears a close resemblance to the country along the South and Middle forks of the Holston, being rather level and composed of low, grass-covered hills, which are largely cleared. The mountainous areas are high and steep, showing a great deal of exposed rock and being in places densely forested.

The fall of Roan Creek is considerable, being about 400 feet between the mouth of Doe Creek and a point about 2 miles below Mountain City, Tenn., a distance of 10 miles, making the average fall 40 feet to the mile. Between Shoun Crossroads and the mouth of Mill Creek, however, the fall is much less, and there are stretches where the current is very sluggish and the stream placid. The country rock is no longer a limestone—quartz rock, gneiss, and slate having made their appearance. Although this stream drains so large an area and has so great a fall its waters are used by very few mills.

The first mill on the stream is the roller flour mill operated by Cole & Scott, a short distance above Butler, which has a capacity of 30 barrels a day and is operated by a turbine working under a head of 12 feet. The next mill is 14 miles above Butler and is a combined gristmill and sawmill using a fall of 12 feet and a very small amount of power. The only other mill on the stream is Baker's gristmill, opposite Rhea Forge, where there is a fall of 18 feet.

Roan Creek reached its minimum stage during the fall of 1900. It was measured on August 13 and was carrying 5.2 second-feet. The average flood rise is about 5 feet, though there are records of a much higher rise in 1861 and in 1870, when the stream rose to a height of 8 feet.

Doe Creek.—This stream rises near Mountain City, Tenn., and flows in a direction generally parallel to the course of Roan Creek, from which it is separated by Doe Mountain, joining that stream about 6 miles above Butler. It drains a broad, flat valley which forms a part of Johnson County Cove, and furnishes more utilized power than Roan Creek, its waters being used for the operation of seven small mills.

Mill Creek.—Of the numerous small streams tributary to Roan Creek from the east and southeast none seen were of sufficient importance to justify gaging with the exception of Mill Creek, which enters from the southeast near Baker Gap. This creek was gaged near its mouth and its drainage basin was traversed from end to end. Near

ELK CREEK, NORTH CAROLINA.

ELK FALLS ON ELK CREEK, NORTH CAROLINA.

Roan Creek the proportion of cleared land is very small, but farther up the basin widens, and near the stream all the land has been cleared and is cultivated in corn and wheat or sodded in grass. The cleared land amounts to between one-fourth and one-third of the total area drained by the stream. About 100 yards above the mouth of the creek is Wilson's gristmill, a small mill containing two runs of stones, one for corn and one for wheat, the power necessary being developed by a 16-foot overshot wheel of about 30 inches face, yielding about 12 horsepower.

Town Creek.—This was the only other tributary of Roan Creek that was gaged. It was measured at Shoun Crossroads. There is one small mill on the creek containing two runs of stones, one for corn and one for wheat, and using 5 or 6 horsepower, which is developed by an undershot wheel.

ELK CREEK.

The next important tributary of Watauga River is Elk Creek (see Pl. XXIV), which rises at Banner Elk Creek, on the slopes of the mountain known as Hanging Rock, and flowing in a general direction a little north of west is joined near Elk Park by Cranberry Creek and Little Elk Creek, after which it turns to the north, entering Watauga River about 2 miles above Butler. A gaging station was established on this stream at Lineback, not far above the mouth, where daily readings of the stage of the water surface have been made.

The average fall per mile throughout its length is very great, the headwaters being at an elevation of about 4,000 feet above sea level. Near the mouth the fall seems to be less than the average, and there are large areas of cleared land and broad, level bottoms, from which, however, the wooded mountain slopes rise very sharply to considerable heights. There are small tracts of cleared land as far up the stream as Elk Mills. Between that place and the North Carolina line there is practically no clearing, but beyond the State line the country is more thickly settled and the areas of cleared land are more numerous. The latter are, however, of little importance compared to the total area of the drainage basin. No accurate estimate of the relative proportions of the wooded and cleared lands could be obtained, but it seems safe to say that the amount of clearing is less than 5 per cent of the area.

The amount of power along this stream is very great, but no attempts have been made to utilize it, and it seems improbable that efforts in that direction will be made for many years to come, unless some sawmill requires power to cut the timber which exists in such abundance over the basin. Perhaps the most noteworthy of the powers is Elk Falls (see Pl. XXV), where there is one of the most picturesque bits of scenery to be found in this country. Here there is a straight plunge of 26 or 28 feet, and in the first mile below it the

river falls 53 feet more, while in the 4 miles above it the fall averages 100 feet to the mile.

Above the latter point and as far as Banners Elk there are numerous shoals and rapids which would furnish small and compact powers with from 10 to 40 feet fall; but there is no demand for power in the present state of the country. Near the headwaters, and in particular near Banners Elk, the fall in the stream is very slight, the creek flowing through semimarshy areas and swampy meadows or peaty bogs covered with a dense growth of laurel, and the mountain slopes are covered with fine timber, spruce predominating, though many other varieties occur.

Throughout the basin the slopes are without exception steep, ranging as high as 50 degrees in some cases, and seem to be covered with a deep soil. The country rock over the lower part is a limestone, that of the upper part gneiss and quartz rock. The soil of the immediate valley is fertile and well adapted to agriculture, the principal crops being grass, corn, and wheat, with some buckwheat and sorghum cane. Many varieties of very fine apples are also grown.

The area being so largely forested the flow of the stream is large, the water never falling very low nor rising to great heights, and though the slopes are steep the high water lasts several days. The creek rises about 5 feet at the mouth.

The famous iron mills at Cranberry are located within the basin of this stream.

BEECH CREEK.

The next stream tributary to the Watauga is Beech Creek, which rises on the northern slopes of Beech Mountain, at an elevation of about 5,000 feet, and flows in a general northwesterly direction, joining the river about 4 miles above the State line. It drains a considerable area of steep, high, and densely forested mountain slopes, a very small proportion of the land being cleared. The cleared areas are confined exclusively to a small tract in the basin of Fogey Creek, which joins Beech Creek a short distance above its mouth, and to some of the narrow bottoms and small hills along the main stream for 2 or 3 miles above its mouth. The total area cleared amounts to possibly 5 per cent of the whole basin. Near the mouth of the stream the country rock seems to be a very good quality of granite, but as the creek is ascended this soon gives place to gneiss. The stream never falls very low, and during high water it rises about 4 feet at the mouth, that being the elevation of the highest mark that was found.

BEAVERDAM CREEK.

Beaverdam Creek, the next tributary entering from the north, rises near Baker Gap and Locust Gap, and flowing in a general southeasterly direction joins the Watauga just to the west of the small mountain known as Dyer Knob. For a mile or more above its mouth this

stream is in a deep gorge, the sides, which are very steep, rough, and rocky, and entirely wooded, rising from the water's edge. The fall of the stream in this gorge is considerable. None of it, however, is now used, but the remains of an old mill are to be seen. In this section and for some distance above Leander active timbering operations are now in progress, but so far very little timber seems to have been cut. Above this the valley widens, the hills are lower and the slopes less steep, and much of the land is cleared and under cultivation in grass or grain. On the fork which rises near Baker Gap almost all of the land is cleared except the tops of the hills and probably one-half or more of the country drained by the other forks. Of the total area drained by Beaverdam Creek probably one-half is cleared land, with a deep and fertile soil. The stream attained its minimum flow in the fall of 1900. The maximum rise at its mouth is about 4 feet.

LAUREL CREEK.

Laurel Creek is the next stream of importance to join the Watauga. It enters from the south, after draining a large basin. The creek valley is very rough and inaccessible for about 2 miles above its mouth, the gorge being deep and the sides in many cases sheer walls of rock. The fall in this distance is very great, being 600 or 700 feet. Above this the fall is much less, though it is still large, and a small part of the area has been cleared and placed under cultivation, the clearing being confined to the comparatively level lands lying near the stream and amounting to probably about 5 per cent of the whole basin. The hillside slopes are steep and forested and the soil is generally deep and fertile, although in some places it is shallow and full of rock fragments. Along the upper portions of the stream the soil is swampy in places and seemingly quite acid and in its present state unsuitable for cultivation.

Extensive lumbering operations have been begun in this basin and much timber has been cut on the hillsides, a great many logs being seen in the stream channel awaiting high water to carry them downstream.

It is said that this stream has never before reached a stage of flow as low as during the summer of 1900. The average flood height at the mouth is about 5 feet.

COVE CREEK.

Cove Creek, which enters the river from the north, is the principal tributary in this part of its course and one of the largest entering the stream. It rises near State Line Gap and flows in a general southerly direction for 14 or 15 miles, draining a broad and very fertile valley, which in comparison with the larger part of the watershed of Watauga River is thickly settled. It is estimated that about one-third or a little more of the basin is cleared land, largely in grass, as stock

raising is the principal industry throughout this country, as it is farther to the north. Throughout this valley, with the exception of the mountain slopes to the east and west, the hillside slopes are rather gentle—rarely reaching 30 degrees, the average being not more than 20 degrees—and the bottom lands are broad, with a deep and fertile soil. While the soil of the hillsides is less fertile, it produces very good crops of wheat and corn. From an agricultural standpoint the basin of this stream seems to be more valuable than any part of the watershed of the Watauga yet described.

At times the creek reaches a very low stage of flow, but never lower, it is said, than that attained during the summer and autumn of 1900. The average maximum rise at the mouth is about 5 feet; 6 feet is sometimes reached, and there is one report of a rise of 8 feet several years ago, probably when a destructive flood affected the entire basin of the river.

DUTCH CREEK.

Above Cove Creek the first tributary is Dutch Creek, which enters the river at Valle Cruces. This creek rises on the southern slopes of Hanging Rock and flows in a general northerly direction, draining an area which is very largely forest covered, containing not more than 20 per cent of cleared land, which is for the most part confined to the comparatively level land immediately along the creek. The mountain slopes are high, steep, and quite rugged, and are covered with the original dense forest growth. Like the other streams of the region, the creek reached its lowest stage during the summer of 1900. Its maximum rise at the mouth is from 3 to 4 feet.

LAUREL CREEK.

Laurel Creek is a small tributary entering the Watauga from the northeast, about 2 miles north of Shulls Mill. It drains a very small area, but carries a large quantity of water in comparison with the area drained, the basin being almost entirely forest covered. The cleared land is confined to a few small areas close to the river, these forming less than one-eighth of the basin. The hillside slopes are rugged, steep, and very rocky, and for the most part are covered with a dense forest growth. The stream reached its minimum flow during the summer of 1900. It rises 3 feet in its maximum floods.

BOONE FORK.

Immediately above Shulls Mill the Watauga is divided into two forks, the one to the east being known as the Boone Fork and the one to the west as Watauga River. The Boone Fork rises on the eastern slope of Grandfather Mountain and after flowing almost due east for 3 or 4 miles turns to the north and flows in that direction for about 4 miles, or to its junction with the main fork of the Watauga. There

are no roads along this stream, and its entire basin is inaccessible. The information that was gathered concerning it was obtained from persons dwelling in the country near by. The stream has a great fall, the headwaters rising at an elevation of about 5,000 feet, while the elevation at the junction with the Watauga is about 2,950 feet. Approximately 1,000 feet of this is concentrated in the first mile below the head of the stream, making the average fall per mile below that point between 165 and 170 feet. So far as could be learned none of the fall is used except by the Stonewall mill, a small sawmill and gristmill just above the junction with the Watauga. The sawmill is operated by a Leffel turbine yielding 15 horsepower under a head of 12 feet, which at low stages of the stream requires practically all of the water flowing. The gristmill is operated by three homemade center-discharge wheels working under the same head, but the amount of power given off by them could not be ascertained.

The entire area drained by the Boone Fork is high, rugged, and very mountainous, almost entirely covered with a dense and luxuriant forest growth. The soil is deep and porous, holding back the storm waters to some extent and feeding them out gradually to the stream, which has a large flow, never falling very low. Notwithstanding the great slope of the stream bed and of the hillside slopes, the floods are not so violent as would be expected.

In Part II of this paper, published as Water-Supply and Irrigation Paper No. 63, will be found descriptions of the drainage basins and water powers of the Nolichucky, the French Broad, the Saluda, the Broad, the Catawba, the Yadkin, the New, and other streams of the region.

[For index, see end of Part II, Water-Supply Paper No. 63.]

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DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 63

WASHINGTON
GOVERNMENT PRINTING OFFICE
1902

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

HYDROGRAPHY

OF THE

SOUTHERN APPALACHIAN MOUNTAIN REGION

PART II

By HENRY ALBERT PRESSEY

WASHINGTON
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1902

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CANE CREEK, TRIBUTARY OF NOLICHUCKY RIVER, SHOWING CHARACTERISTIC ROCKY BED OF MOUNTAIN STREAMS.

HYDROGRAPHY OF THE SOUTHERN APPALACHIAN MOUNTAIN REGION.

PART II.

By HENRY A. PRESSEY.

DRAINAGE BASINS—Continued.*

NOLICHUCKY RIVER.

PHYSICAL FEATURES.

This river is formed by the junction of Toe River and Caney River about 8 or 9 miles east of the Tennessee State line. Toe River is formed by the union of the North Toe and the South Toe between Sevenmile Ridge and the Burn Mountains. The area drained by the Nolichucky in North Carolina is in the high mountains within the limits of Yancey and Mitchell counties.

Yancey County is preeminently mountainous, the Black Mountains penetrating it from the southeast and extending to its center, or to near Burnsville. The great Unaka Range separates the county from Tennessee, and numerous cross chains intersect its surface in all directions, leaving very little valley land except along the banks of the streams. As elsewhere in the region, the mountains here are fertile to the top, being covered with a deep and friable soil which bears trees of great size, and where cultivated produces all of the grains and grasses, as well as very excellent fruits, the apples being especially fine. Cattle raising is an important industry.

Mitchell County lies between the Blue Ridge on the south and east and the Unakas on the north, and like Yancey County is very mountainous, there being little valley land except along the headwaters of Toe River. The cultivated lands are very fertile. All of the cereals grow well, grasses flourish, and fruits of very fine quality are produced in abundance.

The tributaries, like the main stream, rise near the summits of the mountain chains and flow over rocky and precipitious beds through narrow valleys. One of these rocky stream beds is shown in Pl. XXVI, a view of Cane Creek, one of the large tributaries of the Nolichucky.

*Continued from Part I, Water-Supply Paper No. 62.

The river first flows almost north for several miles, then turns toward the northwest and flows in a deep gorge through the Unaka Mountains (see Pl. XXVII) and into Tennessee, where preserving its general westerly direction it finally enters French Broad River about 7½ miles southeast of Morristown, draining a total area of 640 square miles above the Tennessee line, comprising almost all of Mitchell County and all of Yancey County. It leaves the mountains near Embreville, Tenn., which was the western limit of the investigation, although some observations were made of the character of the country lying to the west, sufficient to establish the fact that it differed in no important respects from the area already described as the Valley of East Tennessee.

None of the small closed drainage basins or sinks which are so numerous in the valley of the Holston were seen in the basin of the Nolichucky, but there seems to be a greater number of large springs.

RAINFALL.

The rainfall over the basin is about 51.2 inches per annum, 11.4 inches of which falls in the spring, 15.7 inches in the summer, 11.6 inches in the autumn, and 13.5 inches in the winter. The whole area is subject to sudden and violent rains, producing great floods, while in the winter the ice moving downstream sometimes forms ice dams which do a great deal of damage. The streams are therefore of much less value as sources of power than they otherwise would be. The effect of floods on the Nolichucky is shown in Pl. XXVIII.

FORESTS.

A very large part of the basin is still covered with the original forest. It is estimated that of the 640 square miles in North Carolina 78 per cent is forested, owing, doubtless, to the inaccessibility of the country. It is thought, however, that deforestation will begin in the near future, since in the summer of 1900 the Ohio River and Charleston Railroad was completed as far as the mouth of Caney River, and it is probable that the area drained by that stream will be lumbered at once, as already small spasmodic efforts in that direction have been made. Small sawmills run by water power have been built on a number of the smaller tributaries, and in a few instances splash dams have been constructed for the purpose of driving the logs over the rocky ledges of the mountain streams. Pl. XXIX, *A*, shows a splash dam on Little River, Tennessee, which raises the water 35 feet. Pl. XXIX, *B*, shows a characteristic combined sawmill and gristmill of Yancey County, with its immense overshot wheel.

MINERALS.

The area is very rich in minerals, Mitchell and Yancey counties, as already stated, furnishing a large part of the world's supply of mica. Many varieties of gems also occur, such as emerald, aquamarine,

GORGE OF NOLICHUCKY RIVER.

VIEW SHOWING EFFECT OF FLOODS ON NOLICHUCKY RIVER.

amethyst, and tourmaline. Some corundum has been found, and there are large deposits of iron ore, notably in the small stream valley of Bumpass Cove, where the iron is mined to supply the furnace at Embreville, which has a capacity of 150 tons of pig iron a day.

DISCHARGE MEASUREMENTS.

During the investigation a temporary gaging station was established on the Nolichucky near Chucky Valley, Tenn., where gage-height readings were maintained and measurements were made as shown in the following table. The river was also gaged near Erwin, Tenn., and numerous miscellaneous measurements were made on its tributaries, as shown by the table on pages 108 and 109.

Discharge measurements of Nolichucky River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-ft.*
Sept. 5	Near Chucky Valley, Tenn	L. V. Branch and E. W. Myers.	2.0	302
Sept. 20	do	do	2.18	442
Oct. 15	do	do	2.0	378
Nov. 10	do	do	2.9	919
Aug. 23	Near Erwin, Tenn	L. V. Branch	20.67	770
Sept. 4	do	do	21.53	411

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in the above table which were made near Chucky Valley. In making the measurements near Erwin, however, bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In the latter cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

WATER POWERS.

The fall of the river is very much less than would naturally be expected in a stream draining so high and mountainous an area, the total fall between the junction of the North and South Toe and Embreville being only about 850 feet in a distance, following the course of the river, of about 40 miles, an average of about 21 feet to the mile. Throughout this part of its course the river flows through a gorge with steep and rocky sides, and although there are numerous places where dams could be constructed, and although the fall per mile is large, the opportunities for developing the power are meager, for building room is lacking and the construction of raceways would be costly. Good railroad facilities exist here, since an extension of the Ohio River and Charleston Railroad passes along the river bank.

About 1½ miles below the mouth of Caney River, where the stream is about 200 feet wide, there is a fall of 25 feet, or a little more, in a distance of a half mile, but as elsewhere throughout this portion of its course, there is no building room close to the river, though sites could be found near the summits of the hills.

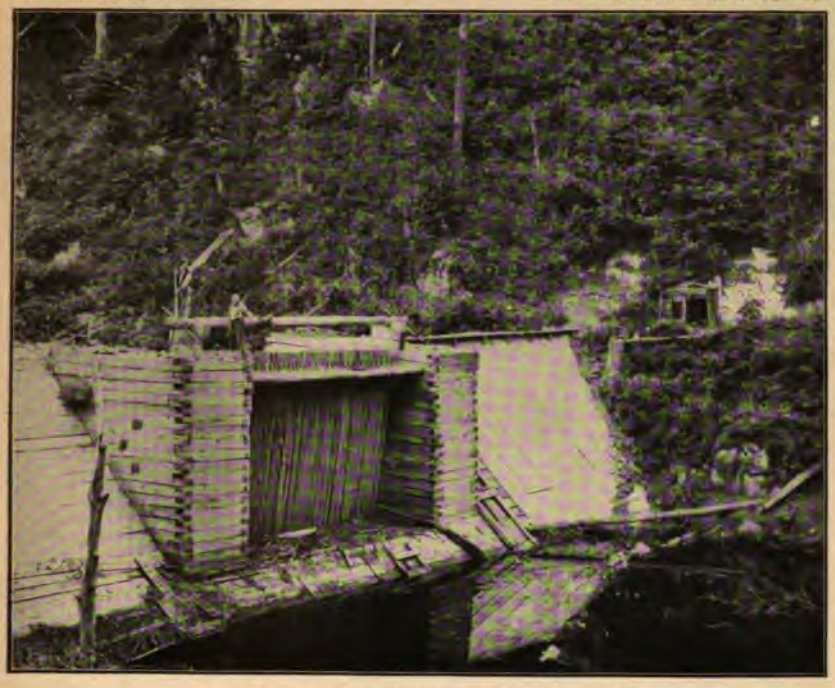
TRIBUTARIES OF NOLICHUCKY RIVER.

DISCHARGE MEASUREMENTS.

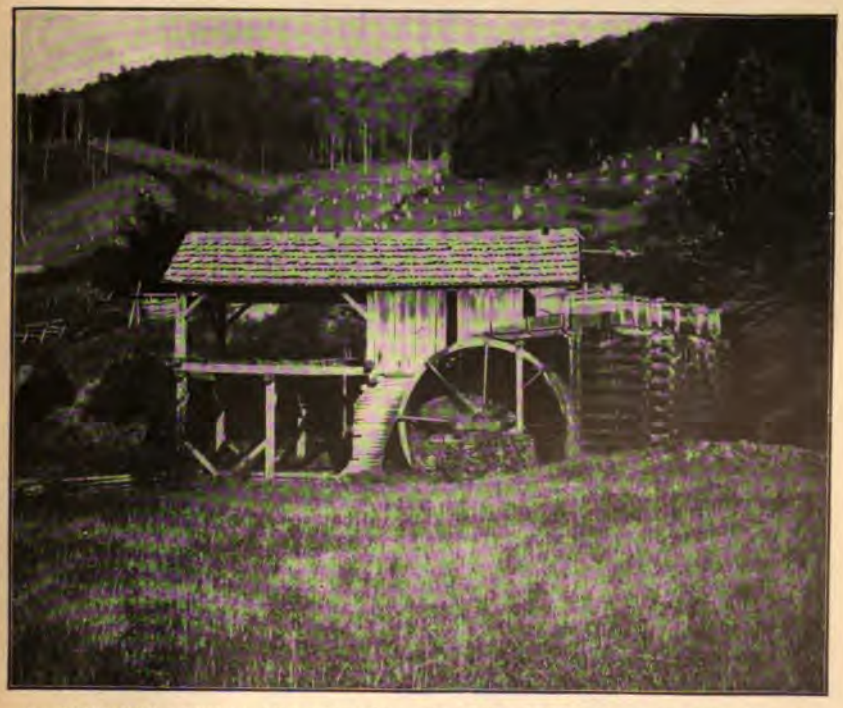
The drainage basins of the principal tributaries of the Nolichucky down to Embreville, Tenn., were visited and the following measurements were made, in order upstream:

Discharge measurements of tributaries of Nolichucky River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-ft.*
1900.					
Aug. 22	Rock Creek	100 yards above mouth, Tennessee	L. V. Branch	3.69	6.37
Do	North Indian Creek.	Unicoi, Tenn	do	4.58	37.9
Do	do	Erwin, Tenn	do	3.95	51.0
Sept. 4	do	do	do	4.19	22.0
Sept. 19	do	do	E. W. Myers	4.05	29.7
Oct. 16	do	do	L. V. Branch	4.18	26.13
1901.					
June 18	do	do	E. W. Myers		174.0
1900.					
Aug. 23	Martin Creek	Near Erwin, Tenn	L. V. Branch	1.59	7.55
Sept. 4	do	do	do	1.68	6.45
Aug. 23	South Indian Creek.	do	do	5.38	52.3
Sept. 4	do	do	do	5.49	33.2
Sept. 19	do	do	E. W. Myers	5.40	53.0
Aug. 23	Hollow Poplar Creek.	Ford of Erwin-Bakersville road, North Carolina.	L. V. Branch	8.15	5.98
Oct. 16	do	do	do	8.26	2.61
Aug. 24	Toe River	Near Huntdale, N. C	do	15.89	381.0
Oct. 17	do	do	do	16.12	301.0
Aug. 27	North Toe River	At ford of Linville-Cranberry road, North Carolina.	do	3.60	18.0
Do	do	Plumtree, N. C	do	7.55	79.0
July 2	do	Near Sprucepine, N. C	H. A. Pressey		333.0
Aug. 26	do	do	L. V. Branch	18.20	105.0
Oct. 21	do	do	do	18.37	78.0
Oct. 25	do	do	do	17.15	570.0
Aug. 24	Pigeon Roost Creek.	At mouth, North Carolina	do	7.39	14.5
Oct. 19	do	do	do	7.47	4.12
Aug. 24	Big Rock Creek	Ford of Huntdale-Bakersville road, North Carolina.	do	2.42	51.3
Oct. 19	do	do	do	2.64	34.5
Sept. 3	Jack Creek	At mouth, North Carolina	do	6.09	8.71
Oct. 19	do	do	do	6.10	6.83
Sept. 3	Pigeon Creek	do	do	5.86	1.65
Oct. 19	do	do	do	5.85	1.26
Aug. 24	Cane Creek	One-half mile above mouth, North Carolina.	do	9.20	11.78
Oct. 19	do	do	do	9.26	9.92
1901.					
Oct. 21	do	Bakersville, N. C	E. W. Myers		22.82
Oct. 22	do	do	do	0.99	21.05
1900.					
Aug. 25	Brush Creek	Lower ford of Burnsville-Sprucepine road, North Carolina.	L. V. Branch	1.39	4.37
Oct. 20	do	do	do	1.51	0.72
Aug. 25	Crabtree Creek	Ford of Burnsville-Sprucepine road, North Carolina.	do	*7.97	15.2
Oct. 20	do	do	do	7.91	14.55
Aug. 25	Snow Creek	Wing, N. C	do	3.03	2.0
Aug. 26	Bear Creek	Flatrock, N. C	do	3.76	4.67
Oct. 20	do	do	do	3.70	3.73
Aug. 26	Grassy Creek	Sprucepine, N. C	do	5.21	6.09
Oct. 20	do	do	do	5.13	9.15
Aug. 26	Beaver Creek	Near Sprucepine, N. C	do	4.50	3.29
Oct. 21	do	do	do	4.29	3.08
Aug. 26	Threemile Creek	Near old post-office at Elsie, N. C	do	5.38	2.63
Oct. 21	do	do	do	5.30	3.57



A. SPLASH DAM ON LITTLE RIVER, TENNESSEE.



B. COMBINED SAWMILL AND GRISTMILL ON PRICE CREEK, YANCEY COUNTY, N. C.

Discharge measurements of tributaries of Nolichucky River—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
Aug. 27	Hensons Creek	At mouth, North Carolina	L. V. Branch	6.94	4.8
Do	Plumtree Creek	Plumtree, N. C	do	2.99	8.09
Do	Roaring Creek	At mouth, North Carolina	do	7.89	15.57
Do	Squirrel Creek	One-fourth mile above mouth, North Carolina.	do	3.12	11.2
Aug. 28	Horse Creek	At mouth, North Carolina	E. Graves	5.55	9.08
Oct. 24	do	do	L. V. Branch	5.15	40.53
Aug. 27	Whitecoak Creek	do	do	2.26	8.36
Do	Kentucky Fork of North Toe River.	do	do	2.85	9.7
Aug. 31	South Toe River	One mile above mouth of Three Fork Creek, North Carolina.	do	4.34	26.0
Oct. 26	do	do	do	3.30	101.0
July 1	do	Ford of Micaville-Sprucepine road, North Carolina.	H. A. Pressey		230.8
Aug. 25	do	do	L. V. Branch	8.08	79.8
Aug. 30	do	do	do	7.98	86.23
Oct. 27	do	do	do	7.23	282.9
Aug. 30	Cane Branch	Ford of Micaville-Marion road, North Carolina.	do	3.92	2.98
Oct. 26	do	do	do	3.78	8.59
Aug. 30	Little Crabtree Creek.	Just above lower ford of Micaville-Sprucepine road, North Carolina.	do	4.28	17.54
Oct. 27	do	do	do	4.23	21.67
Aug. 30	Brown Creek	Ford of Micaville-Marion road, North Carolina.	do	3.02	4.94
Oct. 26	do	do	do	2.85	9.43
Aug. 30	Whitecoak Creek	At mouth, North Carolina	do	4.66	4.40
Oct. 26	do	do	do	4.28	19.86
Aug. 30	Locust Creek	do	do	1.98	3.83
Oct. 26	do	do	do	1.87	7.96
Aug. 31	Colbert Creek	Ford of Micaville-Marion road, North Carolina.	do	3.87	2.51
Oct. 26	do	do	do	3.50	7.24
Aug. 31	Middle Creek	do	do	3.94	3.78
Oct. 26	do	do	do	3.64	9.20
Aug. 31	Rock Creek	do	do	1.96	6.92
Oct. 26	do	do	do	1.62	28.68
Aug. 31	Three Fork Creek.	One-fourth mile above mouth, North Carolina.	do	1.49	9.49
Sept. 1	Caney River	Near Big Tom Wilson's, North Carolina.	do	1.33	17.11
Oct. 18	do	do	do	1.34	13.9
Aug. 24	do	Huntdale, N. C	do	3.69	89.9
Sept. 3	do	do	do	3.82	62.77
Oct. 17	do	do	do	3.83	58.3
Sept. 2	Big Creek	At mouth, North Carolina	do	2.83	5.67
Oct. 17	do	do	do	2.89	2.0
Sept. 2	Little Bald Mountain Creek.	do	do	4.91	2.12
Oct. 17	do	do	do	4.90	2.61
Sept. 2	Bald Mountain Creek.	One mile above mouth, North Carolina.	do	3.43	19.7
Oct. 17	do	do	do	3.55	10.6
Sept. 2	Elk Shoal Creek	At mouth, North Carolina	do	1.63	1.29
Do	Bald Creek	Near Burnsville, N. C	do	4.56	16.25
Oct. 18	do	do	do	4.56	9.97
Sept. 2	Price Creek	do	do	2.48	9.46
Oct. 18	do	do	do	2.53	8.35
Sept. 1	Bowlems Creek	do	do	5.03	3.45
Oct. 18	do	do	do	4.97	4.02
Sept. 1	Cattail Branch	do	do	2.78	2.77
Oct. 18	do	do	do	2.64	4.69
Sept. 1	Elk Fork Creek	Near Big Tom Wilson's, North Carolina.	do	1.24	4.78
Oct. 18	do	do	do	1.28	1.49

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

Descriptions of the drainage basins and water powers of the larger of these tributary streams are given on the following pages, in order upstream.

NORTH INDIAN CREEK.

Around Erwin, Tenn., and up North Indian Creek there is a very picturesque farming country. The creek drains a large area, the upper part of which is mountainous, with steep slopes, while near the Nolichucky it broadens out into a fertile valley. The low-water discharge was measured and found to be 22 second-feet. On this creek, at Unicoi, Tenn., the Unaka Milling and Lumber Company has a large wood-working plant and gristmill. Their power (about 40 horsepower) is developed by 20-inch and 24-inch turbines working under a head of 16 feet. Just above Unicoi an old ore washer formerly utilized a fall of 30 feet, but it is now out of use. On Dick Creek, a tributary of North Indian Creek, there are four falls averaging 30 to 40 feet each. In the limestone cove on North Indian Creek there are four gristmills using the water power. This cove is a widening of the valley of the creek, and in it are a number of good farms under cultivation. Much limestone is found over this entire section of country. Two miles above Erwin, on the Nolichucky, J. T. Wilder has a sawmill and wood-working plant. The dam across the stream is 17 feet high and backs the water in the river three-fourths of a mile. About 80 horsepower is developed by one turbine.

SOUTH INDIAN CREEK.

Entering the river from the south, about 2 miles above Erwin, is South Indian Creek, a stream in many respects similar to North Indian Creek, though the proportion of cleared land in its basin is somewhat less.

The creek rises on the northern slope of the Unaka Mountains, draining an area the upper part of which is made up of high, steep, and rugged mountain slopes, which as a rule are very densely forested. As the stream is descended, however, the mountains recede from it and leave broad and fertile bottoms, which are entirely cleared and under cultivation, grass, corn, and wheat being the principal crops. The cleared areas form a very small part of the whole basin, however, probably less than 10 per cent.

A great deal of timber is being cut in this area, particularly near the heads of the smaller tributaries near its mouth, and there are several small sawmills located on the creek which cut part of this product, the remainder being worked upon the spot by the small portable sawmills which are moved from place to place as the timber is cut.

At the time the stream was visited in September, 1900, its discharge was very low—about 33 second-feet. It is said to have reached a lower stage during the summer and fall of that year than ever before. The flood rise at the mouth is between 7 and 8 feet.

HOLLOW POPLAR CREEK.

This stream, which receives its drainage from the eastern slope of the Unaka Mountains, has a low-water flow of about 6 second-feet. Excepting the lower 2 miles, where there are several small farms, the creek valley is very narrow, with almost no land under cultivation. The side hills are steep and are heavily covered with timber and underbrush. The slope is greater than that of either North Indian Creek or South Indian Creek, the total fall from source to mouth, a distance of 5 miles, being about 2,000 feet. The fall is greatest near the headwaters, where it is a mountain stream jumping from ledge to ledge down the side of the mountain. There is no cleared land except near its mouth, the steep slopes being covered with the original forest growth.

NORTH TOE RIVER.

The North Toe rises on the western slope of the Blue Ridge, in the northeastern part of Mitchell County. Its course is circuitous, flowing first to the southwest, then to the west, and then to the northwest, receiving numerous tributaries, the chief of which is the South Toe, which unites with it on the line between Mitchell and Yancey counties. Practically the whole of Mitchell County is drained by the North Toe and its tributaries, the Nolichucky proper receiving the drainage from the extreme western part of the county, a small part of the northeastern section draining into Elk Creek, a tributary of the Watauga, and another small portion of the eastern section being drained by Linville River.

The region of the headwaters of the North Toe is very rough, with steep mountain slopes and narrow valleys sparsely populated. Along Whiteoak Creek and for a distance on the main stream and the Kentucky Fork above their junction the valley is wide and flat, but is heavily timbered. Part of it is in a rather swampy condition and is covered with heavy laurel thickets. Below the mouth of Whiteoak Creek the mountains close in and form a narrow and steep gorge as far down as Horse Creek. There the valley widens out a little, and from there down there is some bottom land under cultivation on each side of the river.

The tributaries of the river in this section and as far down as Sprucepine flow directly from the mountains in narrow gorges. They are for the most part short streams with great fall but with little water. The only cleared land along them is within a half mile of their mouths or on top of the mountains from which they flow, the mountain sides being too steep for successful cultivation. Throughout the region from the head of the river and its tributaries down to Sprucepine and to the mountain summits on either side probably not more than one-sixth of the land is cleared. The cleared areas are

nearly all planted in wheat and corn, although a small portion is in grass, for grazing purposes. A few miles above Sprucepine the mountains recede from the river, leaving a very wide valley, which extends down to the Cane Creek Valley on the north side of the river and to Caney River on the south side. This valley is rather hilly throughout most of its area, and the land is cleared on the north side between Sprucepine and Bakersville. On the south side most of the cleared land is around Burnsville, although there are a number of farms near Sprucepine and along Grassy Creek.

One mile above the mouth of Pigeon Roost Creek and just above the ford there is a very good site for the construction of a dam. A water power of considerable magnitude could be developed here. Lying to the south of the main channel of the river is an island which rises about 15 feet above the water level and is never overflowed, not even during the highest floods. There is a heavy fall in the river, and by the construction of a dam from the end of the island to the north bank of the stream all of the water could be turned into the narrow channel behind the island and a fall of 15 feet or more be obtained.

Above this point there are many shoals, the river having a large fall throughout that part of its course, flowing in a deep gorge, with sides rising at angles of 30 to 40 degrees. There are several small mills on the upper part of the river, but the larger portion of the power developed in the basin is derived from the tributaries, the needs of the mills requiring the development of only a few horsepower at any place. Powers of considerable magnitude, however, can be developed on these streams, for notwithstanding the amount of water carried by each one is small the fall obtainable in a short distance is large, and absolutely safe locations for buildings can be obtained, which is not always the case on the main river.

The first mill of any size on the North Toe is just above the mouth of Bear Creek. It is a gristmill, mica-grinding mill, and wood-carving establishment. The owners have developed a 6-foot fall and claim to have about 75 horsepower. At Elsie, farther upstream, there is a combined flour mill, sawmill, and gristmill with a small dam giving a 10-foot fall.

Just below the mouth of Plumtree Creek Vance Brothers have a combined mica mill and sawmill, using a large part of the low-water flow in the river with a 36-inch Samson turbine under an 11-foot head. Mica is abundant throughout this district, and is mined extensively from Plumtree Creek down the river as far as Big Rock Creek on the north and Caney River on the south. In this district there are also several water powers developed for grinding mica.

The swift-flowing tributary streams of the North Toe, with their numerous vertical falls, furnish abundant power for small mills, and a number of the power sites have been developed, though in a small way.

On Pigeon Roost Creek, which enters Toe River 2 miles above the mouth of Caney River and has a low-water flow of about 14½ second-feet, there are two large mills, the first a small sawmill and gristmill about 100 yards above its mouth, utilizing a fall of 16 feet; the second one a sawmill and gristmill 3 miles upstream, using an overshot wheel.

There are only two rolling mills in Mitchell County—one on Big Rock Creek, belonging to Henry Master and having a capacity of 30 barrels per day; the other on Cane Creek, just below Bakersville, and having about the same capacity. At Magnetic, on Big Rock Creek, there is a large mica mill, and at the mouth of Beams Creek is located Garland's mica mill, using a 15½-inch Leffel wheel. On Cane Creek there is a sawmill just above its mouth, and at Wing, on Snow Creek, J. C. Phillips has a sawmill and gristmill using two overshot wheels of 14 and 15 feet diameter, respectively. Above this mill there are two small gristmills on Snow Creek.

On Crabtree Creek, 4 miles above the mouth, there is a fall of 100 feet, 40 feet of which is in a clear vertical leap. Six mica mills, run by one turbine under 116 feet head, are located at this place. On Bear Creek there are two small corn mills with a fall of 20 feet and 12 feet, respectively. On Beaver Creek there is a combined sawmill and corn and wheat mill run by an overshot wheel and a Leffel turbine with an 18-foot fall. Farther up the stream there is a small corn mill run by a 16-foot overshot wheel.

On Hensons Creek (marked Powdermill Creek on atlas sheet—an obvious error, for Powdermill Creek is the unnamed tributary just above it) there are three mills. The lower one is a small gristmill run by a tub wheel. Above this is Houston's sawmill, gristmill, and planing mill, run by a Leffel wheel under a 35-foot head. The upper mill, Green's sawmill, has an overshot wheel and 23 feet fall. On Plumtree Creek there is a mill, run by using the 12-foot fall on a turbine wheel, making pins for telegraph wires. One mile above, on the same creek, there is a mica mill using 91 feet fall on a turbine. Still higher up on Plumtree Creek there are four small corn mills. Powdermill Creek, Hensons Creek, Roaring Creek, and Squirrel Creek, running down the sides of the mountain, have almost unlimited falls but little water. The discharge of these streams at their lowest stages is as follows: Hensons Creek, 4.8 second-feet; Powdermill Creek, barely 1 second-foot; Roaring Creek, 16 second-feet; and Squirrel Creek, 11 second-feet.

By far the largest tributary of the North Toe is Big Rock Creek, which with its tributary Little Rock Creek rises on the southern slope of the Iron Mountains, which form the dividing line between Tennessee and North Carolina. They receive a large part of the drainage from those high and rugged mountains, the culminating peak of which is Roan High Knob, with an elevation of 6,313 feet. Cloudland, a noted summer resort on this peak, affords one of the finest

views obtainable from any of the summits of the Appalachian Mountains. Here is a very comfortable summer hotel, pure water, cool climate, and all that goes to make a pleasant and healthful summer resort. A narrow-gage railroad passes through Roan Mountain Station, 12 miles from Roan High Knob, from which point a good road has been built up the mountain side. When on Roan Mountain the Black Mountains, Hawks Bill, Table Rock (on Linville River), and the mountains of Virginia and Tennessee are in full view. One can but wonder why more is not known of these mountains and why the visitors are so few. It is, however, probably a matter of only a few years before this region will be one of the great mountain resorts of the country.

SOUTH TOE RIVER.

This river rises in the southern part of Yancey County, N. C., and flows directly north into the North Toe. It receives its drainage from the eastern slope of the Black Mountains and the western slope of Sevenmile Ridge. It follows close to the base of the latter ridge, which rises abruptly from the water's edge. On the west side of the stream the steeper slopes of the Black Mountains are about 2 miles from the river, leaving a narrow valley between. There are, however, no farms on either side of the stream, and even in the narrow valley on the west side only a few tracts (hardly one-fifth of the area) have been cleared for cultivation. Considering the drainage basin from the river to the mountain summits on both sides, probably not 1 per cent of the land has been cleared. About 2 miles above the mouth of the river the mountains on both sides recede, leaving the land from that point to the North Toe level compared with the rest of the region, although it is still a very hilly country.

Little Crabtree Creek, with a minimum discharge of 18 second-feet, is the largest tributary of the South Toe. It rises near Burnsville, in the foothills of the mountains, and joins the river a short distance northeast of Micaville. The river has seven other small tributaries, ranging in size from 2.5 to 9.5 second-feet at their lowest mid-summer flow.

There is not a mill on the South Toe, and only one or two small corn mills on its tributaries. The steep watershed and the short tributaries carry the rainfall quickly to the main stream, causing rapid fluctuations and high floods, making mill improvements difficult and expensive. This probably accounts for the few power developments in the watershed.

CANEY RIVER.

This river also rises in the southern part of Yancey County and flows northward uniting with Toe River to form the Nolichucky. It receives its drainage from the western slopes of the Black Mountains

and the eastern slopes of the Bald Mountains, and has a minimum discharge of about 63 second-feet from a drainage area of about 158 square miles. The western slopes of the Black Mountains are similar to the eastern slopes, which are drained by the South Toe, being steep and heavily wooded, the forest growth changing from the foot to near the top, where little except balsam is able to stand the low temperature. Near the foot of the mountains large areas are covered with heavy laurel thickets.

Unlike the South Toe, most of the cleared land along Caney River is in its upper and middle portions, while along its lower course the stream flows through a valley so narrow that it may be considered almost a gorge. The valley above Burnsville, however, is wider than that of the South Toe and has a larger percentage of cleared land. One mile below Burnsville the river enters a narrow gorge through which it runs for about 3 miles, but even here the higher lands are largely cleared. Farther down, the country is flat and well cleared for 6 or 7 miles; then the river enters the narrow gorgelike valley through which it flows, with many twists and turns, around the mountain knobs to its mouth. In this gorge there are very few places wide enough for clearing, but on the mountain sides the land is cleared except in the steepest parts. During the last summer (1900) the Ohio River and Charleston Railroad was extended up Nolichucky River as far as the mouth of Caney River, and since that time much lumbering has been done in this section, as already mentioned. Of the area drained by Caney River perhaps one-fourth is cleared. Fully one-half of the valley land is cleared and is largely under cultivation. Wheat and corn are the principal crops. Near the head of the valley lives Big Tom Wilson, one of the earliest settlers in this region and the man who found Professor Mitchell after his ill-fated expedition and untimely death.

The only tributaries of Caney River of any size are Bald Creek, which has a low-water flow of 16 second-feet, and Bald Mountain Creek, which has a low-water flow of 20 second-feet. There are other smaller tributaries, ranging in their low-water discharge between 1.3 and 9.5 second-feet.

Only one water power on Caney River has been developed, and this by a small gristmill located about halfway between Burnsville and the mouth of the river. A large tract of land at the headwaters, including the northwestern slope of Mount Mitchell, is owned by Colonel Murchison, of New York, who holds it as a game preserve.

FRENCH BROAD RIVER.

GENERAL FEATURES.

French Broad River rises on the eastern slope of the Tennessee Ridge, between Jackson and Transylvania counties, N. C., flows in a general northeasterly direction across Transylvania and Henderson

counties, a distance of about 30 miles, then northward across Buncombe County, a distance of more than 20 miles, then northwesterly across Madison County, a distance of 20 miles, through the Great Smoky Mountains and into eastern Tennessee, where it is joined by the Nolichucky and the Holston, and finally enters Tennessee River, its waters eventually reaching the Mississippi and the Gulf of Mexico. For convenience the drainage basin has been divided into two parts: (1) The area drained by the river in North Carolina, and (2) the area drained by it in Tennessee.

WATERSHED IN NORTH CAROLINA.

The portion of the drainage basin of French Broad River in North Carolina is comprised within the limits of Transylvania, Henderson, Buncombe, and Madison counties. The small streams from the mountains in the upper part of the watershed soon reach the wide plateau and unite into a broad and sluggish river, with practically no shoals or falls. Little clearing has been done on the upper watershed, but an extension of the Transylvania Railroad has just been completed as far as Jeptha, for the purpose of transporting lumber. The terminus of this extension is called Toxaway. The larger part of the land around the headwaters of the main stream as far as the North Fork is owned by the Toxaway Company, and they expect very soon to commence extensive lumbering operations.

Through all of this region springs are numerous, and the water is pure and cold. Above Jeptha there is very little pasture land, but the region appears to be well adapted to grazing. The mountains around the head of the North Fork are high, many of them reaching an elevation of 6,000 feet. They are traversed by trails only, the forests being still in a wild condition and the region but sparsely populated. The watershed of the North Fork as a whole is not thickly wooded, but no timber cutting has been going on for a long time. Most of the land east of this stream, including the large area of Pisgah Ridge, is owned by Mr. George W. Vanderbilt and is under the care of an expert forester. Above Jeptha the mountains close in to the banks of the stream, and consequently the branches are short and the slopes steep. Between the mouth of Tucker and Shoal creeks, on the North Fork, are some excellent shoals, but no suitable locations for large buildings, although there are shelves of rock on each bank throughout the entire distance. The fall here is about 30 feet in 200, consisting of three drops about 100 yards apart, with rapids intervening. The water power has not yet been utilized.

The drainage area of the river above Asheville is 987 square miles; the total drainage area in North Carolina 1,745 square miles. Of this total area at the time the Tenth Census was taken 1,091,000 acres were under cultivation and 8,079,000 acres, or 78 per cent of the whole, were still forest covered. In 1890, according to information

gathered for the Eleventh Census, about 30 per cent of the area was cultivated land, and as the rate of clearing has been accelerated during the last decade, on account of the large development of the lumber industries, it seems safe to conclude that at the present time about 40 per cent of the whole area is either cultivated land or land from which the timber has been removed.

Transylvania County, in which are the headwaters of the river, is a true mountain region, having on its southern boundary the Blue Ridge in its most massive and imposing form, and being the starting point of the great Pisgah and Balsam ranges, which stretch through the county toward the north. The only exceptions to the rugged topography are the broad and fertile valleys of the French Broad and its tributaries, which are cultivated and in a high state of improvement, being among the most valuable and productive farming lands in the State. These valleys are the scene of an important stock-raising industry, which is the principal source of revenue, though enormous crops of cereals and grasses are produced, some tobacco is raised, and fruits of large size and fine flavor are grown. The greater part of the county is still in the original forest growth of the usual varieties found in these mountains, which attain great size on account of the surpassing fertility of the soil. There are extensive areas of white-pine timber which will yield fairly good lumber. The merchantable trees of walnut and cherry have been largely removed, though an occasional walnut of fair size is seen, and small tracts of cherry are said to exist on the higher mountain slopes. Large tracts of poplar are also to be found, and but little oak has been cut. It is estimated that of the total area of the county only about 15 per cent is cleared land.

There has been no development whatever of the mineral wealth of Transylvania County, though gold, silver, lead, copper, nickel, asbestos, corundum, and mica are said to exist in the vast wilderness of the Balsam and the Pisgah mountains.

Henderson County is the northward or downstream continuation of the valley of the French Broad, and its topographic features are similar to those of Transylvania County, except that its areas of comparatively level and fertile land are larger and the general aspect of the country is less mountainous. A remarkable feature is the apparent great depression of the surface and the width of the stream valleys, some of which assume, as on Mud Creek, the character of a wide swamp. This depression is, however, apparent and not real, the most depressed portions being above the level of the Blue Ridge plateau. The hillside slopes are very gentle.

The soil on the uplands is not remarkably fertile, being a light-gray gravelly or sandy loam. The soil in the valleys is in large part alluvial, with much vegetable matter, and yields large crops of grains, grasses, vegetables, and fruits. Corn grows well, especially in the valleys, but the principal agricultural industry is the production of

cabbages and other vegetables for market. A great deal of fruit is also grown, and is either canned or dried.

Along the stream valleys of Henderson County pine is the predominant growth, but on the uplands oak, chestnut, hemlock, and pine are to be found, while near the summit of the mountains and in the cold and sheltered coves walnut, cherry, maple, and an occasional white pine are seen. The lumber industry, however, is of small importance, though some logs have been floated to Asheville, and small amounts of timber are cut annually for local uses. Some tan bark is also gathered.

Although the proportion of comparatively level land in this county is very great, a smaller proportion of the area is cleared than in either Madison County or Buncombe County, the cleared land amounting to about 31 per cent of the whole, according to the returns of the Eleventh Census, and only small amounts of clearing have been done since that time, so that it is improbable that the cleared land now amounts to more than 35 per cent of the entire area.

The country rock throughout Henderson County is for the most part a gneiss, but the valley of Boylston Creek is in a schistose limestone of a gray-blue color, which in places carries thin veins of quartz. The mineral wealth of the county is greater than that of either Madison County or Buncombe County. What is said to be the largest deposit of zircon in the United States occurs in the valley of Green River, and gold is found at the Boylston mine, on the southeastern slope of Forge Mountain, 13 miles west of Hendersonville.

The general surface of Buncombe County, the next county to the north, is more hilly than mountainous, with stream valleys narrow and limited in extent, which, however, offer good facilities for agricultural operations. Between Asheville and Alexander the country on the north side of the river as far as could be seen was gently rolling, with slopes of from 5 to 15 degrees, about two-thirds cleared and largely cultivated in grass. On the south side of the stream the country preserves the same general character, but the hillside slopes appear gentler, averaging between 5 and 10 degrees, about the same proportion of land being cleared. The forest growth, which for several miles back from the stream is in small segregated areas—too small to affect the run-off—is more largely pine than in the basins heretofore described. A number of tributaries rising in the gaps of the mountains enter the main stream, adding much to the beauty of the scenery. Every year great numbers of tourists visit the valley of the French Broad in search of health or pleasure. Pl. XXX is a view on Swannanoa River, one of the favorite streams of nature-loving tourists.

The upland soils in Buncombe County are stiff, even-grained loams, rarely sandy, generally deep, being derived from the disintegration *in situ* of gneiss, and are on the whole very fertile. The soils on the lowlands are rich sedimentary loams, with much vegetable matter

SWANNANOA RAPIDS ON SWANNANOA RIVER, NORTH CAROLINA.

along the smaller streams. Along the larger streams are loams similar in character to those on the smaller streams, but more sandy and less fertile. The hills erode rapidly when unprotected, but are generally quickly seeded with grass, producing a retentive turf.

The soils produce all of the cereals, grasses, and fruits, wheat yielding 10 or more bushels to the acre. Oats do well. Corn thrives, producing from 30 to 40 bushels to the acre, while clover and the grasses yield fine crops of hay. In recent years more and more attention has been paid to the raising of beef cattle for market, and this is now an important industry throughout the county. Many chickens and turkeys are also raised, these selling for good prices. Of the fruits, apples are produced in greater abundance than any other, and they are of large size and fine flavor. All vegetables grow well, the cabbages being particularly good. Tobacco is largely cultivated along the river and on the hills a few miles back from it, these localities seeming best adapted to its production. A good grade of bright tobacco is obtained.

The timber in Buncombe County includes all of the varieties found in the mountains—oak, hickory, walnut, beech, birch, chestnut, locust, pine, spruce, and others, with a dense undergrowth of dogwood, laurel, azalea, and other shrubs. There are large mills sawing lumber at Asheville and many small ones in close proximity to the timber. A considerable quantity of tan bark is also shipped from the county, the oak stocks being generally sold for fuel after being barked, but as a rule no use is made of the hemlock stocks. Walnut, curly birch, and curly ash are shipped in the log to veneering factories, but the merchantable trees of this class have been largely removed, and poplar and cucumber trees, which furnish the chief building materials of the region, are also becoming scarce. Timber that can be floated, such as pine, poplar, and chestnut, has been largely removed to supply the mills at Asheville, but little oak has been cut. According to the returns of the Eleventh Census, about 25 per cent of the area of the county was at that time cleared land. Since then, however, much clearing has been done, so that it is estimated that at the present time 40 per cent of the area is cleared; some estimates place the amount of cleared land at 50 per cent, and it is generally stated that about two-thirds of the cultivable land is cleared. Mr. George W. Vanderbilt is the largest owner of forest lands in the county. He owns many thousand acres to the south and east of Asheville, and modern scientific methods of forest management have been inaugurated in all forests owned by him.

As has previously been stated, the country rock of Buncombe County is principally a gneiss, though there are areas of granite, and across the southern edge of the county there is a narrow belt of slates and schists. The mining industry is unimportant. Talc is met with occasionally, nickel is seen in very small quantities, and a serpentine of good quality occurs in abundance between Weaverville and Leices-

ter, but the vein has never been worked. Magnetic iron ore has also been found at several places. It is said that many years ago some of the latter veins were worked; and a deposit has recently been opened at the Blackwell mine, near Blackwell Springs. Limonite is found in many places throughout the county, and brick clay is abundant. The latter is made into common and pressed brick at several yards, some fire brick is made, and a plant at Biltmore formerly manufactured drain and roofing tile and paving brick.

Mineral springs of divers kinds are abundant, those carrying sulphur being the most noted. There are also numerous nonmineral springs, which furnish large amounts of water to the streams.

The country roads furnish the chief means of transportation throughout the county, and while there has been a movement for good roads, particularly in the region near Asheville, the greater portion of the country roads are poorly graded and become almost impassable in the winter, on account of mud.

Madison County, the next county through which the French Broad flows, is also essentially a mountain country, there being very little valley land and the whole area being traversed by mountain ridges ranging in height from 2,500 feet to 4,500 feet above sea level. None of the ranges, however, rise to so great heights in this county as they attain in the adjoining counties, even the Great Smokies being below their average elevation. The soil is very fertile and produces fine crops, though from the almost entire absence of transportation facilities the agricultural products are limited to little more than enough to supply the inhabitants, a very small amount being raised for market. The hills are especially adapted to the production of a good grade of bright tobacco, large quantities of which were formerly grown and marketed in Marshall or Asheville, but recently, on account of the low prices obtained, this industry has suffered a diminution, and the "deadening," as the exhausted tobacco fields are known locally, are to be seen on many hillsides, either uncultivated or growing corn or other grain. Stock raising produces a large annual revenue, which could be considerably increased.

The mineral wealth of the county is known to be large, but it is mostly undeveloped. Magnetic iron ore, chromic iron ore, manganese, nickel in small quantities, corundum, serpentine, talc, and baryta are all found. Some corundum has been mined and shipped, much baryta has already been taken out and is still being mined by many individual miners. Recently a talc mine has been opened near Stackhouse, which is said to produce a very good quality of that mineral.

The timber found throughout Madison County is remarkably fine. Walnut trees 8 feet in diameter, poplars 10 feet in diameter, wild cherry, black birch, and buckeyes 3 or 4 feet in diameter are met with occasionally, while the common timber trees, such as oak, chestnut, and pine, are plentiful and of large size. Much timber has already been taken out and much is still being logged wherever the crude

FRENCH BROAD RIVER AT PAINT ROCK, N. C.

methods of lumbering prevalent can reach it. There are large mills at Stackhouse and at Putnam, and small portable mills are located wherever the timber can profitably be attacked, the lumber being wagoned to the railroad for shipment.

The geologic formations of the county are similar to those of Cocke County, Tenn. Close to the State line there is a belt of sandstone, which is succeeded by slates and schists. About a mile below Hot Springs the latter give place to limestone and dolomite, which above the springs are succeeded by sandstones, slates, and schists, and these in turn by the gneisses and granite which are the predominant rocks of the county.

The Hot Springs mentioned as being located in the limestone belt constitute one of the most interesting features of the region. They are 6 or 7 miles above the Tennessee line, directly on the banks of the river, some springs indeed bubbling up in the bed of the stream. As the name indicates, the water is warm, although of varying degrees of temperature, and possesses many valuable medicinal properties, said to be particularly efficacious in rheumatic cases. There is a large hotel at the springs, and many people come to take the hot baths, for which the waters are chiefly used.

Throughout its course in Madison County the river flows in a deep gorge which it has carved out in the gneisses and slates, now twining among the hills and now cutting through them, leaving at the latter places almost perpendicular walls of bare rock several hundred feet high or slopes of from 50 to 60 degrees covered with a sparse growth of gnarled and stunted trees clinging to the interstices of the rock.

Pl. XXXI is a view of the river at Paint Rock, near the North Carolina–Tennessee boundary, and shows both the forested slopes and the perpendicular rock walls in this portion of its course. As the river is ascended the sides of the gorge become gradually lower and less steep, and the country beyond the crests of the river bluffs loses somewhat its mountainous character, becoming instead a region made up of rounded hills and swells, with broader and more nearly level valleys between, a much larger proportion of the land being cleared, the cleared areas increasing from practically none on the extreme northern, western, and southwestern borders to probably 50 per cent of the area above the mouths of Walnut and Pawpaw creeks.

Throughout this area none of the closed basins which have been so notable a feature in some other areas were noted, but instead there seems to be a greater number of small stream channels, most of them carrying some water, which was not the case over a large part of the area drained by the South Fork of the Holston.

WATERSHED IN TENNESSEE.

The part of the drainage basin of the French Broad which is situated to the east of the town of Newport, Tenn., the western limit of the investigation, is comprised entirely within the limits of Cocke

County. The area immediately about Newport and for 5 or 6 miles to the east while hilly is not mountainous, and in many respects bears a close resemblance to the country seen along the South and Middle forks of Holston River, consisting, as it does, of rather low hills and broad ridges of gentle slopes largely cleared and grass covered. In parts of this area, particularly in the part seen from the road leading from Parrottsville to Newport, numerous small closed drainage basins or sinks were observed, many of them of large size and having pools of water in their bottoms. Occasionally, over an area of a square mile or more, these sinks occur in such numbers as to absorb the entire drainage, permitting, so far as could be observed, no water to find its way into the stream channels. This will tend to produce complications when the run-off from two similarly situated areas is compared if either area contains basins. None of the basins were noted above the North Carolina line. There are numerous springs of chalybeate and sulphur water in Cocke County, and large numbers of springs whose waters possess no medicinal properties.

It is along this part of the course of the stream that the far-famed scenery of the French Broad occurs, but with all its beauty the scenery barely equals that seen when the summit of the river bluffs has been reached, where vistas of mountain and meadow, woodland and stream are spread out before the eye, scenery of which the rugged beauty of that along the river has given no promise.

If the whole area of Cocke County be considered, about 40 per cent of the land is cleared and cultivated, according to the best information obtainable; but this includes a part of the vast Unaka mountain chain, with its outlying spurs and ridges, where the proportion of cleared land is exceedingly small, so that it is estimated that from 65 to 70 per cent of the area to the west of the mountains is cleared and under cultivation or in grass, which is one of the principal products.

The mountains rise very abruptly and steeply from the more level area, and the proportion of cultivable land on them is small, being confined to the stream valleys and to a few of the lower and gentler slopes. In some of the coves and gorges the soil is productive, but these areas are too small to be of value for grain growing. They are, however, adapted to the production of grass and fruit, although very little has been done in that direction. The principal valley is of course that of the main stream, which has an average width of about 1 mile and is exceedingly fertile, the soil, which is alluvial, being deep and producing, with good cultivation, from 50 to 100 bushels of corn to the acre, this being the principal crop. Oats thrive very well, wheat not so well. Of late years more of the land has been sown to grass, and the stock-raising industry now affords a considerable revenue to the people of the county. The price of land ranges from $1 and $2 to more than $50 an acre.

There is some very fine timber in Cocke County, mainly oaks of

various kinds, chestnut, maple, hickory, walnut, white and yellow pine, spruce, and other varieties. Formerly a great many shingles were made, mostly from white pine. A limited amount of lumber is sawed annually by the small country mills for local uses, and a much larger amount of timber is annually destroyed for the purpose of stripping tan bark or for railroad ties; but taken as a whole the timber industry is of little importance, and the same is true of manufactures in general. There is a small cotton mill at Newport, also one or two small sawmills and a flouring mill, and there are small sawmills and gristmills at various places in the county, but they are of little importance.

The mineral wealth in this section is very great, but so far as could be learned nothing has been done toward developing it. Iron is said to occur in paying quantity, also lead and baryta. Newport is just at the junction of the shales and the limestone, which there form a narrow valley, and for 5 or 6 miles up the river limestone and dolomite occur, the prevailing color being blue, though layers of gray rock are also found. The limestone and dolomite are succeeded by red shales, and these, for a fourth of a mile or more upstream, by white or grayish sandstones. Passing these sandstones, shales or slates are again met with, bands of conglomerate occurring at intervals, also a few layers of dolomite. The sandstone then makes its appearance again and continues several miles up the river, or to and beyond Paint Rock.

RAINFALL.

The total annual rainfall at Asheville is 42.6 inches, distributed as follows: Spring, 11.7 inches; summer, 13.8 inches; autumn, 7.7 inches; and winter, 9.4 inches. Asheville, however, is in a region of rather low precipitation compared with the rest of the mountain country, although the records of the station at Waynesville show that the annual precipitation between Asheville and Paint Rock is very near the amount stated. Records of stations above Asheville show that the annual rainfall increases very rapidly as the stream is ascended, and near the headwaters, but across the divide, are stations having a mean annual precipitation of between 72 and 73 inches, with an occasional record of more than 105 inches.

The distribution of the rainfall is favorable to a large annual run-off in the stream, since at the time when plant life and evaporation make the heaviest demands upon the precipitation the rainfall is greatest, and it is least in autumn and winter, when these demands are at a minimum. However, since the autumn precipitation is the least and plant life and evaporation are still rather active, the stream is then subject to periods of low flow, although the run-off per square mile is large when compared with streams draining areas out of the mountains, and remains so during even the periods of severe drought.

TRANSPORTATION.

Throughout the greater part of the basin of the French Broad the transportation facilities are poor, being mainly confined to the ordinary country roads, which as a rule are steep and rough, poorly graded and ill kept. The Knoxville branch of the Southern Railway follows the course of the stream very closely below Asheville, and the Spartanburg branch of the same system runs approximately parallel to it for a long distance in the upper part of its course, while the Murphy branch furnishes railroad facilities for the inhabitants of the valley of Hominy Creek. The Hendersonville and Brevard Railroad has recently been constructed from Hendersonville to Jeptha, in Transylvania County, furnishing an outlet for the products of the upper part of the basin. But owing to the character of the country the transportation facilities are less effective than they otherwise would be, and there seems no present prospect that the conditions will be bettered, though one or more additional lines of railroad have been projected to traverse the basin. On the whole, however, the transportation facilities of the area are better than those of any other section of western North Carolina, and in consequence it is better known to the outside world and is more prosperous than the areas to the northeast and the southwest.

DISCHARGE MEASUREMENTS.

During the investigation a gaging station was established on the French Broad at Oldtown, Tenn., where measurements were made from time to time, also at other places along its course, as shown in the following table. The Survey has maintained a gaging station at Asheville since September, 1895, the results of which have been published in the annual reports.

Discharge measurements of French Broad River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-feet.*
Sept. 4	Oldtown, Tenn	E. W. Myers and L. V. Branch.	1.00	867.0
Nov. 2	do	do	1.26	1,653.0
Dec. 15	do	do	1.30	1,975.0
Dec. 26	do	do		2,901.0
Sept. 7	One-half mile above Hot Springs, N. C.	L. V. Branch	19.35	938.0
Sept. 12	Alexander, N. C.	E. W. Myers	17.15	840.0
Oct. 29	do	L. V. Branch	16.27	2,068.0
Sept. 18	Fanning Bridge, North Carolina	N. C. Curtis	16.22	1,161.0
Oct. 17	do	do	16.95	614.0
Sept. 17	Penrose, N. C.	do	19.80	1,160.0
Sept. 13	Near Carson Creek, N. C.	do	13.80	286.5
Oct. 15	do	do	13.90	206.5
Sept. 14	Eastatoe Bridge, North Carolina	do	12.40	113.0
Oct. 15	do	do	11.21	102.4

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in the above table at Oldtown. In making all of the other measurements, however, in each case a bench mark was established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In these cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

MOUNTAIN ISLAND SHOAL, FRENCH BROAD RIVER, NORTH CAROLINA.

WATER POWERS.

In describing the fall and power of the French Broad we will start near Newport, Tenn., and follow upstream to its source. At the starting point, about 2 miles north of Newport, the river is a comparatively placid stream, flowing between willow-bordered banks and through broad and fertile grass-covered bottom lands, and this character is preserved for 5 or 6 miles, when there is an abrupt descent of about 4 feet over a rock ledge extending straight across the stream. Near these falls the bottom lands almost entirely disappear and the mountains begin to close in on the river, the hillside slopes, which are sparsely forested, varying from 30 to 50 degrees. Farther upstream an occasional broad bottom is to be seen, but the mountains continue to rise higher and higher as the stream is ascended, the river entering a gorge which reaches a very highly developed stage near Paint Rock. (See Pl. XXXI.) Throughout this distance, however, there is little concentration of fall in the stream, the fall averaging about 10 feet to the mile, following the course of the river, which is very tortuous in this section.

The stream preserves the same general character as far as Hot Springs, the average fall per mile between Paint Rock and Hot Springs being about the same as in the section between Paint Rock and Newport. Above Hot Springs, however, the character of the river changes abruptly, and from a smooth though rapid stream it becomes a tumultuous mountain torrent, dashing along among many huge bowlders and over the rock ledges which obstruct its course and project above the surface in jagged ridges, twining and curving around the hills between lofty and steep walls of rock, which are thinly clad with stunted trees. The river contains many islands and is in places very wide.

In the 7.7 miles between Hot Springs and the mouth of Brush Creek the total fall is 201 feet, giving an average fall of 26.1 feet per mile. There are several places in this distance where the fall is noticeably concentrated. The first of these is about one-fourth of a mile above Hot Springs and is known as the Mountain Island Shoal. At this shoal, shown in Pl. XXXII, a high and rocky island about 200 yards long divides the stream into two parts. The most noticeable concentration of fall is at the ends of the island, there being at the lower end an almost vertical plunge of between 4 and 5 feet, and at the upper end two plunges of about 3 feet each. There is also a fall of about 4 feet in the distance between these plunges, making a total fall of about 15 feet at this place. Below the island the river contracts suddenly to a width of about 100 feet and the water is very deep and sluggish. The railroad is on the north bank, crossing the stream a short distance below the island, and as the track is only a few feet above the level of high water, it offers an obstacle to the

development of the power. A development could be made, however, but at considerable expense, by constructing a wing dam from the upper end of the island diagonally toward the north bank, gradually decreasing the height of the dam upstream. This would throw as much of the water as might be desired to the south side of the island and away from the railroad, and then by building a dam across the south channel near the lower end of the island the flow of the stream could be controlled. Space for a power house on the island could be cleared by a small amount of blasting, and the power be transmitted to Hot Springs, where there is a large area of level land. This is by far the largest and most noticeable fall on the stream, and probably would afford a cheaper and easier development than any other.

As at this fall, so at all others between Paint Rock and Asheville, the proximity of the railroad to the stream renders it impossible to build high dams, though otherwise the conditions for easy and cheap construction are very favorable, for everywhere stone can be obtained in great quantities at comparatively small cost for blasting and transportation to the site of the work.

Although the average fall per mile in the stream channel between the head of the Mountain Island Shoal and the mouth of Brush Creek is very great, there are several places where it is still more concentrated, the first of these being just above the mouth of Laurel Creek, where the fall is estimated to be about 15 feet in a little more than one-fourth of a mile, and about 2 miles below Barnard Station, where there is another large fall within a short distance. Just below and a little above the mouth of Brush Creek there is still another large fall, the banks being very high, steep, and rocky, the stream comparatively narrow, and all of the conditions for the construction of a high dam very favorable, excepting the presence of the railroad. At almost any desired place within this distance—from the Mountain Island Shoal to Brush Creek—falls of from 15 to 20 feet can be obtained.

From the mouth of Brush Creek to Asheville, a distance of 29.3 miles, the stream is still very rapid, but the average fall per mile is much less than in the section just described, being about 15.4 feet, in general well distributed. Sites where falls of 10 feet or more can be obtained are numerous, though none of them were noted particularly.

The first power developed on this stream is at Marshall, Madison County, where, on the south bank of the river, the Marshall Milling Company has erected a flour mill with a capacity of 75 barrels per day, utilizing only a small part of the flow, which is turned aside by means of a wing dam about 200 yards long extending diagonally upstream about half the width of the river, from the upper end of which a very low dam has been built to the north bank of the stream, both dams being made of logs and giving a fall of 13 feet at the wheel.

There are several other localities between Marshall and Asheville where small powers could be developed in the same way, but no attempts have been made to do this. There is a project to develop a small fall in the stream just below Asheville, to obtain power to operate street cars and electric lights, and a low dam has been built, but no other work has been done.

Above Asheville the character of the stream again changes and it becomes a placid river with a current which though rapid when compared with the streams of the Coastal Plain is very sluggish when compared with its mountain neighbors or with its own current a few miles below. The bed of the stream is overlain with a stratum of coarse sand and gravel, and in general is rather smooth, though the current is interrupted at intervals by ledges and bowlders, and the fall is very much more gradual and evenly distributed than is usual with mountain streams. The distance from Asheville to Brevard, by river, is 48.35 miles, and the total fall is 130.9 feet, making the average fall per mile only 2.7 feet. Indeed, so small is the fall that at one time the United States engineers did a great deal of work on this portion of the stream to render it navigable. Formerly a small steamboat plied the river, but it did not pay expenses, and of late no attempt has been made to navigate the stream.

There are two principal obstructions to navigation, the first of these 8½ miles above Asheville, and known as the Sandy Bottom Shoal. This is the largest shoal on this part of the river, the total fall being 22.6 feet in a distance of 18,000 feet. Three and one-half miles above this is the Long Shoal, where the fall is 18.3 feet in 12,920 feet. Above this and as far as Eastatoe Ford, about 1 mile above Jeptha, the stream flows placidly along through a broad and level valley and offers no possibility of power development. Above the ford, however, the fall rapidly increases, but the stream divides into the North and West forks, both of which are too small for consideration as power streams.

TRIBUTARIES OF FRENCH BROAD RIVER.

DISCHARGE MEASUREMENTS.

During the investigation the drainage basins of the important tributaries in North Carolina were visited and the following measurements made:

Discharge measurements of tributaries of French Broad River in North Carolina.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
Sept. 14	North Fork of French Broad River.	Two hundred yards above mouth of West Fork.	N. C. Curtis		100.6
Oct. 15	do	do	do	13.2	51.8
Sept. 16	do	Bridge on Brevard-Webster road.	do	14.98	107.48
Do	do	Ford on road between Tucker and Shoal creeks.	do	7.3	75.0

Discharge measurements of tributaries of French Broad River in North Carolina—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
Sept. 14	West Fork of French Broad River.	Near mouth	N. C. Curtis	2.20	149.0
Oct. 15	do	do	do		62.0
Sept. 14	Middle Fork of French Broad River.	Bridge 20 yards above ford	do	5.35	77.0
Do	South Fork of French Broad River.	Footbridge at ford of main road.	do	10.3	71.0
Oct. 15	East Fork of French Broad River.	Near mouth	do	10.2	46.0
Sept. 16	Tucker Creek	Two hundred yards above mouth.	do	4.61	28.0
Sept. 13	Cathey Creek	Ford of Brevard-Jeptha road	do	6.7	30.2
Sept. 17	King Creek	Brevard road	do	4.71	15.46
Do	Davidson River	Near mouth	do	16.45	151.77
Oct. 16	do	do	do	16.75	70.30
Sept. 17	Little River	Three-fourths mile above mouth.	do	13.66	182.8
Oct. 16	do	do	do	14.35	69.2
Sept. 17	Boylston Creek	Near mouth	do	5.35	28.65
Do	Mills River	Bridge on Old Haywood road	do	13.11	211.64
Oct. 17	do	do	do	13.4	94.0
Sept. 18	Mud Creek	Near mouth	do	5.11	108.0
Do	Caney Creek	Bridge on Westfall's place	do	10.1	60.0
Do	Avery Creek	Bridge on road from Mills River to Asheville.	do	6.56	11.31
Sept. 19	Hominy Creek	Asheville	do	15.1	80.0
Oct 17	do	do	do	15.4	24.0
Sept. 19	Swannanoa River	Biltmore	do	2.91	76.33
Sept. 20	North Fork of Swannanoa River.	Three miles above Swannanoa.	do	16.07	21.45
Do	Flat Creek	Two miles below Black Mountain Station.	do	4.05	22.83
Sept. 12	Beaverdam Creek	Fifty yards above mouth	E. W. Myers	5.09	1.46
Oct. 30	do	do	L. V. Branch	5.08	4.10
Sept. 16	Lees Creek	Olivette	E. W. Myers	11.15	3.95
Oct. 30	do	do	L. V. Branch	10.95	2.29
Sept. 12	Newfound Creek	At mouth	E. W. Myers	17.75	9.41
Sept. 16	do	Three-fourths mile above mouth.	do	10.19	34.16
Oct. 30	do	do	L. V. Branch	10.44	20.23
Sept. 12	Reems Creek	At mouth	E. W. Myers	12.1	4.89
Oct. 30	do	do	L. V. Branch		9.0
Sept. 11	Flat Creek	do	E. W. Myers	18.05	5.33
Oct. 29	do	do	L. V. Branch	17.43	5.0
Sept. 12	Sandymush Creek	Bailey	E. W. Myers	9.73	21.72
Sept. 17	do	do	do	9.43	55.23
Oct. 30	do	do	L. V. Branch	9.53	45.0
Sept. 16	Turkey Creek	Blackwell Springs	E. W. Myers	7.97	35.24
Oct. 30	do	do	L. V. Branch	8.32	16.24
Sept. 17	Big Ivy River	One-eighth mile below mouth of Bull Creek.	E. W. Myers	2.55	47.59
Oct. 29	do	do	L. V. Branch	2.72	41.72
Sept. 8	Little Pine Creek	One hundred yards above mouth.	do	5.84	3.35
Oct. 31	do	do	do	5.76	6.0
Sept. 8	Pawpaw Creek	One mile above mouth	do	4.6	0.35
Sept. 10	Walnut Creek	At mouth	do	23.24	1.38
Oct. 31	do	do	do	2.35	2.23
Sept. 8	Big Pine Creek	One hundred yards above mouth.	do	6.07	4.65
Oct. 31	do	do	do	6.01	4.45
Sept. 8	Big Laurel Creek	Two hundred yards above mouth.	do	16.13	49.0
Sept. 18	do	do	E. W. Myers	15.77	55.0
Sept. 7	Spring Creek	Near Hot Springs	L. V. Branch	2.00	15.0
Nov. 1	do	do	do	2.07	16.0
Sept. 7	Shutin Creek	do	do	2.61	9.4

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

The principal drainage basins are briefly described on the following pages, in order upstream.

LONG CREEK.

The first tributary of any size entering the French Broad above Newport, Tenn., is Long Creek, which flows in from the north, draining a small area. At the mouth the valley of the stream is very narrow, the mountains rising high and steep on either side, in walls of almost bare rock; but farther up the valley widens greatly, and it is estimated that above the forks about half of the basin is cleared land, being made up for the most part of rather low hills, with gentle side slopes timbered in pine and oak. Corn and wheat are the principal crops; about one-third of the cleared land is in grass.

At the time the stream was visited it was extremely low, its flow being too small to gage, but it was carrying a quantity of water estimated to be between one-fourth and one-third of a second-foot. The stream is said to rise very rapidly after rains, reaching an extreme height of about 4 feet above low water. The floods are of short duration.

BIG CREEK.

Big Creek, the next tributary, enters the river from the south, near Del Rio, draining an extensive area in the high and rugged Stone and Smoky mountains, almost the entire basin being forest covered and very steep and rough, with a great deal of rock exposed on the hillsides. The cleared land is confined entirely to the narrow strips bordering the stream, but it is small in amount, being probably less than 5 per cent of the area of the basin, which may thus be considered entirely forested.

When this stream was visited it was very low, carrying an estimated discharge of possibly 2 second-feet. It rises rapidly after rains, in consequence of the great steepness of the hillside slopes over its basin, and attains a maximum height of from 5 to 6 feet above low water.

LAUREL BRANCH, MOONEYHAM BRANCH, AND ROCK CREEK.

These are very small streams which are practically dry during severe droughts.

WOLF CREEK.

Wolf Creek is the next tributary. It is a small stream entering from the south, draining a long and narrow area which with the exception of one or two small patches of an acre or two near its mouth may be considered entirely wooded. The basin is rough and mountainous, with very steep slopes. The forest growth consists for the most part of pine, with a dense undergrowth and with some oak and chestnut. Extensive lumbering operations have been carried on on

the mountain slopes over the basin, and much of the available timber has been cut, but the ground is densely shaded by the undergrowth and the nontimber trees.

This stream was not gaged, the quantity of water which was flowing, estimated to be about 0.5 second-foot, being too small to admit of measurement. It was stated by residents that the stream was then at its lowest stage. The maximum flood rise is between 4 and 5 feet.

SHUTIN CREEK.

The basin of this stream is similar to that of Wolf Creek, except that very little timber has been cut.

SPRING CREEK.

Spring Creek, entering the river from the south, at Hot Springs, is the largest tributary yet described. It rises in the extreme southern corner of Madison County, near Sandymush Bald, on the northeastern slope of the Newfound Mountains, and flows in a general northerly direction for a distance of about 20 miles, draining an area of 66 square miles. Its basin is in the midst of the high mountains, is steep, rough, and rugged, and is almost entirely forest covered, the cleared land being confined to the narrow stream valleys which constitute a very small proportion of the whole area, probably less than 10 per cent. The stream attained its minimum stage during the autumn of 1900, when it was measured and found to be carrying 0.45 second-foot. It has a maximum rise of about 6 feet during floods, which are said to be violent, but of short duration.

BIG LAUREL CREEK.

This stream, the next tributary of the French Broad, rises in two forks, one in the Bald Mountains, in the extreme northeastern part of Madison County, and the other in the Unaka Mountains, in the extreme northern part of the county. It drains an area of 141 square miles. Its basin is very rough and rugged, with a large proportion of steep, forested slopes, ranging from 15 to 50 degrees and showing a great deal of exposed rock, which is of a slaty character. For a considerable distance above its mouth the stream is in a deep gorge and could not be followed, but it was ascertained that the country was extremely rugged and contained no cleared land. The hills there lack the symmetry of those seen farther upstream, having steeper slopes and being broken into irregular shapes by the small valleys and gullies which extend up their sides.

The proportion of cleared land in the basin is small, not more than 25 per cent of the area being under cultivation. The cultivated areas are for the most part confined to the stream valleys and the lower uplands. Within the last ten years much land has been partially

cleared by cutting away the undergrowth and deadening the larger trees, the deadened areas being largely cultivated in tobacco or corn. The soil is in part red, clayey, and very impervious to water, and in part loamy, and is not very fertile.

Extensive lumbering operations are now in progress over the basin, many small portable mills being located in close proximity to the timber, the lumber being hauled to the railroad at either Putnam or Stackhouse. Poplar seems to be the timber most sought, though oak and pine are also cut. Much chestnut remains, and trees of many other varieties are found.

At its mouth the flood rise of the creek is from 7 to 8 feet. It never falls very low, the lowest stage known having been reached in the autumn of 1900, when the discharge was about 49 second-feet. While the stream is capable of furnishing power in large amounts, it is utilized by only two or three small gristmills, grinding grain for local uses.

Some baryta has been found in the basin, but so far as could be learned the principal deposits of this mineral are along the main river, on the hills between Stackhouse and Marshall. Talc is also found in this region, and some has been recently taken out which is said to be of excellent quality.

Shelton Laurel Creek.—This stream is the principal tributary of Big Laurel Creek. Its drainage basin is very similar to that of the main stream, although as the creek is ascended the topography flattens out to some extent. The stretch of the river between White Rock and Alleghany is much more level and more extensively cultivated than any seen lower down the stream. The only extensive lumbering operations carried on in the basin are in this locality, being mainly directed against the timber which can be reached from the small tributary streams, although the operations are more or less general.

The soil seems similar to that along Big Laurel Creek, but it contains a very large proportion of rock fragments ranging in size from a pea to several inches in diameter, and more quartz is seen, forming now an important part of the country rock.

The slope of the channels of this creek and its branches is very great, the storm waters reaching the streams almost immediately, the main creek rising very rapidly and falling as quickly.

BIG PINE CREEK.

The next tributary gaged was Big Pine Creek, which enters the French Broad from the south, opposite Barnard, draining a considerable area which is largely forest covered, the cleared and cultivated land being confined for the most part to the stream valley and the lower hills. The hillside slopes over the basin are almost uniformly steep and rocky, and the greater part of the area is mountainous.

WALNUT, LITTLE PINE, AND HAYES CREEKS.

Walnut Creek, entering from the north, about 3 miles above Barnard, is a stream of about the same size and general character as Big Pine Creek, except that the proportion of cleared and cultivated land in its drainage basin is considerably greater, the valley of the stream being wider and the slopes less steep and rugged, the topography consisting for the most part of rather low and rounded hills, largely grass covered, although the upper part of the basin is steep and mountainous. The cleared land amounts to probably one-third of the whole area, possibly more. The stream reached a very low stage in the autumn of 1900, lower than ever before known, it is stated. The discharge measured on September 10 was 1.36 second-feet. The maximum rise in flood is about 4 feet.

Little Pine Creek and Hayes Run are entirely similar streams, though much smaller.

IVY RIVER.

Ivy River, the next tributary, enters the French Broad from the east, and is the principal tributary in North Carolina. It rises on the western slopes of the Great Craggy Mountains, near Yeates Knob, the headwaters being at an elevation of about 5,000 feet, and flows in a general westerly direction, joining the French Broad about 2½ miles above Marshall, draining an area of 176 square miles.

For about 3 miles above its mouth the valley of the river is very narrow and the banks of the stream are steep, showing much exposed rock, but they are forested with a growth of considerable density. Above this 3-mile stretch, although the gorge formation still persists for a considerable distance, the hills do not rise to so great heights, and the country beyond the summit of the bluffs is composed of a succession of hills and ridges of moderate height, very sharp topped, and inclosing narrow V-shaped valleys, the hillside slopes ranging from 10 to 30 degrees. A large part of the area—perhaps 75 per cent—is cleared. It is probable that nearly 50 per cent of the whole area drained by Ivy River is either under cultivation or is grass. Throughout this part of its course, or to beyond Grantville, the stream channel is very tortuous.

As the stream is ascended the topography becomes less strongly marked and the country better fitted for agriculture and stock raising, until a short distance below Barnardsville the mountains begin again to encroach on the river and the cultivated lands are confined to the immediate valley of the stream. There is considerable timber yet standing in the high mountains about the headwaters, much of it being inaccessible.

Corundum has been found near Democrat, nickel stainings have been observed in the rocks at many localities, and a vein of serpentine of good quality crosses part of the basin.

The stream has a large fall throughout its length, the average fall per mile between its mouth and Barnardsville, at the junction of the forks, being about 43 feet. It could be made to furnish power in large amounts, but as yet very little has been done in that direction. About 1 mile above its mouth there is a fall of 6 feet in 200 feet, over ledges of solid rock, the width of the stream being between 60 and 70 feet.

The most important power site on the stream is about 2 miles above its mouth. Here Mr. W. B. Ellis, of Asheville, and others, have planned a large power development, which is about half completed. The plans include an arched masonry dam 95 feet in height, 360 feet long on top, 60 feet wide at base, and 12 feet thick to the 83-foot level. The race is to be 860 feet long from the dam to the power house, built partly in embankment and partly in open rock cut, with 100 feet of tunnel and 250 feet of steel flume, which will carry the water to a pair of 22-inch turbines. It is stated that the flow of the stream will be sufficient, with proper storage, to develop 2,000 horsepower under a working head of 110 feet, the natural flow of the stream yielding 1,000 horsepower under that head. The power is to be transmitted electrically to Asheville, Marshall, and other places at a potential of 10,000 or 11,000 volts. During the autumn of 1900, when the plant was last visited, all work had been suspended, due largely, it was rumored, to lack of water.

On the basis of 1,000 horsepower developed continuously, the flow of the stream at this place is calculated as follows: It is safe to assume that the losses of energy in the wheels, dynamos, and in transmission will amount to at least 20 per cent of the total energy due to the water, and as it is the intention to deliver 1,000 horsepower at the end of the transmission line, this will require of the stream a flow capable of developing 1,250 gross horsepower with a head of 110 feet, or 11.36 gross horsepower per foot of fall. One second-foot of water falling 1 foot will yield 0.1135 gross horsepower, so that in order to produce 11.36 gross horsepower per foot fall a flow of practically 100 cubic feet per second will be necessary, and during times of drought the stream does not carry that amount of water. When these notes were made, in October, 1899, although the discharge could not be gaged, it was estimated to be not much more than 50 second-feet. When the locality was visited in the fall of 1900, at a time when the stream was said to be very low, the discharge was gaged a short distance above the head of the backwater from the dam and a flow of 41.72 second-feet was found.

Just above the mouth of Little Ivy River there is a gristmill with an 8-foot dam, giving a fall of 10 feet, and at Democrat there is a similar mill.

SANDYMUSH CREEK.

The next tributary is Sandymush Creek, which joins the French Broad about 4 miles above the mouth of Ivy River. This creek rises on the northern slopes of the Newfound Mountains, in a number of small creeks which have a general northerly or northeasterly course. Including Turkey Creek, which joins it near its mouth, it has a drainage area of 86 square miles. Near its mouth and for a considerable distance upstream the creek lies in a deep and narrow gorge, but farther up the valley widens very much and the topography becomes less strongly marked over a large part of the area. The high hills which inclose the valley are rough and steep, most of them ranging from 15 to 30 degrees, but many of them being much steeper. The proportion of cleared land is smaller than in the basin of Turkey Creek, being less than half of the whole area. Above the junction of Little Sandymush Creek the area is entirely mountainous and forested, with the exception of small, narrow areas immediately along the stream. Pine trees seem more numerous than heretofore noted, the character of the hard-wood growth remaining the same, also the agricultural products. The soil is a fertile loam, the country rock a much laminated and contorted gneiss.

The stream is said to have reached its minimum stage of flow during the fall of 1900 (see measurements in table on page 128). During floods it is subject to violent rises of from 6 to 7 feet.

Turkey Creek.—The valley of this tributary of Sandymush Creek is very different in character from that of the main stream. In proportion to its size its valley is broader than that of any stream yet described. The proportion of cleared land seems to be about 75 per cent over the lower part of the basin, and is probably 66 per cent of the whole area. The topography is a succession of hills and ridges divided by broad valleys, and the hillside slopes are comparatively gentle. The soil is deep and fertile. The country rock seems without exception a gneiss. At the time the stream was visited all of the land except that in corn was covered with grass, and this is true of all this section of country during the fall and summer months. A large part of the area is planted in wheat, and when that is harvested grass quickly covers the land, remaining until seeding time comes again.

The creek falls very low at times, reaching, it is said, its lowest stage in the fall of 1900, and though subject to floods of 6½ to 7 feet, these are rare and generally of short duration.

FLAT CREEK.

The next tributary is Flat Creek, which enters the French Broad from the east, about 1 mile below Alexander. It is a small stream rising on the western slope of the Flat Creek Mountains and draining

a broad and flat valley of considerable extent. The topography is in broad and low flattened hills and ridges, the hillside slopes being very gentle. Seemingly about two-thirds of the area is cleared land, about one-half of it in grass and the other half chiefly in wheat, corn, and tobacco. The soil appears deep and fertile. No exposed rocks were seen, though the basin is underlain by gneiss or granite. The stream is subject to periods of very low flow, and during floods it rises from 5 to 6 feet at the mouth.

REEMS, NEWFOUND, AND BEAVERDAM CREEKS.

Reems Creek, the next tributary, enters the river from the east a short distance above Alexander, and seems in every respect similar to Flat Creek, just described. It was gaged at its mouth, with the results given in the table on page 128. The maximum flood rise is from 5 to 6 feet.

Newfound Creek, entering the French Broad from the southwest, rises close to the headwaters of Turkey Creek, near Turkey Creek Pinnacle, and in soil, topography, and general characteristics is a stream similar to Turkey Creek.

Beaverdam Creek, entering the French Broad from the east a short distance below Owenby, drains a long, narrow, and rather flat valley containing a large proportion of cleared land, but it is a small and unimportant stream.

SALUDA RIVER.

About 10 miles above Greenville, S. C., Saluda River is formed by the confluence of the North Saluda and the Middle Saluda. The South Saluda, a stream nearly or quite as large as the two other streams combined, enters the Middle Saluda a few miles above the junction of the latter stream with the North Saluda. The watershed of these three branches is defined by the North Carolina–South Carolina boundary line, extending from the Greenville-Pickens county line in South Carolina to the western slope of Rocky Spur, 5 miles southeast of Saluda, N. C., the total length being about 36 miles and the drainage area estimated at about 380 square miles. The watershed includes the southern slopes of the Saluda Mountains and a portion of the Blue Ridge. Below the junction of the three forks the main stream flows in a general southeasterly direction through the State of South Carolina, joining Broad River near Columbia, to form the Congaree.

The steep slopes at the headwaters of the river are densely forested, but the valleys of even the smaller tributary streams have been cleared. Oak and hemlock predominate, but pine and other timber are frequently intermingled. The trees are not in good condition, however, owing to frequent scars from fire and other destructive

agencies. The soil is largely composed of material derived from the decomposition of granite and gneiss. In many parts of the basin it has a thick layer of humus and is very fertile; in other parts, however, a clay is formed which is impervious to water and not well suited to agriculture. The soil in the former places will not withstand the action of flowing water, and where the forests have been cut considerable washing of the top soil can be observed. In the lower part of the drainage basin the soil is sandy and is largely devoted to agriculture, the chief crops being cotton, sugar cane, and sweet potatoes.

The Saluda is largely outside of the mountain region, its headwaters only being on the slopes of the Blue Ridge. For this reason it is perhaps not of as great importance in the investigation of the proposed Southern Appalachian Park as the streams which rise and flow for many miles through the mountains. The preservation of the forests, however, is of the greatest importance, owing to the nonresistant character of the soil and the danger of heavy wash and floods.

NORTH SALUDA RIVER.

This stream rises on the western slope of Rocky Spur and Hogback Mountain, at an elevation of 2,600 feet. It is 25 miles long and flows in a general southwesterly direction, joining the Middle Saluda about 3 miles below the confluence of that stream with the South Saluda. The elevation at the junction is about 980 feet. The average fall per mile is therefore about 65 feet. Most of this fall, however, is on the upper portion of the stream, the average fall per mile for a distance of 20 miles above the mouth of the North Saluda being only about 25 feet.

Around the headwaters of the stream about 15 per cent of the watershed has been cleared. The western sides of Rocky Spur, Hogback Mountain, and Glassy Mountain and the eastern slopes of the Saluda Mountains have been very little cleared, while the southern slopes of the latter mountains are especially well wooded. No lumbering is being done in this section, and the land cleared for farming purposes is proportionately small. As a natural consequence of its forested basin the waters of the stream are never very muddy, although they are said to contain more sediment than either the Middle Saluda or the South Saluda.

After leaving the mountains the flood plain of the river broadens, and the wide, flat bottoms are given up largely to agriculture, the chief crop being corn, although considerable cotton is raised. Discharge measurements were taken on the North Saluda 2 miles below Humphries's store, at Lima, and at Marietta, with the results given in the table on page 138. The river has an average annual fluctuation of 10 feet.

Fall Creek, a small tributary flowing into the North Saluda about midway between Humphries's store and Lima, has a fall of about 120 feet to the mile and a mean discharge of 6 or 8 second-feet.

MIDDLE SALUDA RIVER.

The Middle Saluda rises in Jones Gap, in the Blue Ridge, on the North Carolina–South Carolina boundary line, at an elevation of 3,000 feet. Its total length is about 20 miles; the elevation at its mouth 990 feet. It has an average fall of 100 feet to the mile, but, as in the case of the North Saluda, the fall is much greater in its upper portion than in its lower course, the average fall for 10 miles above its mouth being only 11.6 feet per mile.

The drainage conditions affecting the flow of the stream are similar to those of the North Saluda. Its flood plain is quite broad below Riverview and is under cultivation. The soil in the river bottoms is rich and loamy and black in color, while the hills are covered with a deep, rather rich, light-red soil. A large amount of cotton is raised around Marietta, and below that place cotton constitutes the chief crop.

The water power is better than that of the North Saluda. The Cleveland mill, on Mill Creek, a tributary from the east, is a small sawmill and gristmill having a working head of about 12 feet. Below it shoals are quite frequent on the main stream. Opposite Marietta there is a shoal a half mile long, called Long Shoal. The fall is possibly 10 feet in 200 feet. Two miles below the Long Shoal there is a sawmill and gristmill having a dam about 6 feet high and a working head of 12 or 15 feet. The average annual fluctuation of the Middle Saluda is 9 feet.

SOUTH SALUDA RIVER.

This branch has a total length of 30 miles. It rises just behind Pinnacle Mountain, at an elevation of 2,700 feet. The difference in elevation between its head and mouth is 1,720 feet, the average fall per mile 57 feet. It has one large tributary, viz, Oolenoy (sometimes called Illinois) Creek, a stream about 10 miles long, with an average fall of 30 feet to the mile below Sunnydale. It has wide and fertile bottom lands, planted chiefly in corn. The upper watersheds of both South Saluda River and Oolenoy Creek have been practically untouched by the woodman's ax.

The only fall observed on the South Saluda was 8 miles west of the Cleveland mill, just below the bend in the stream. The fall there is 30 feet in 100 feet, but the building space is rather cramped. The flood plain of the river varies in width from 50 to 200 yards, and the soil is deep and rich.

The scenic features of the region surrounding the headwaters of the South Saluda and the Middle Saluda are remarkably striking.

The southern slopes of the Blue Ridge are very steep. Table Rock, a mountain with an elevation of 3,157 feet, is surrounded by an escarpment of bare rock on all sides except one, and presents a very forbidding appearance. There is a popular summer resort, owned by Furman University, on Cæsars Head Mountain.

DISCHARGE MEASUREMENTS.

During the investigation measurements were made of the North Saluda, the South Saluda, the Middle Saluda, and Fall Creek, as shown in the following table. A gaging station has been maintained on the main river at Waterloo, S. C., since August 30, 1896, the results obtained being published in the subsequent annual reports of the Survey.

Discharge measurements of Saluda River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-ft.*
1901. May 24	Saluda River	Greenville, S. C	N. C. Curtis	34.5	1,594.0
1900. Sept. 7	South Saluda River.	Freeman Bridge, below mouth of Middle Saluda River.	do	14.1	223.0
Oct. 14	do	do	do	14.1	171.0
1901. May 3	do	do	E. W. Myers	12.4	469.0
1900. Sept. 7	do	2 miles above mouth of Middle Saluda River.	N. C. Curtis	6.0	188.0
Oct. 14	do	do	do	6.0	134.0
1901. May 3	do	do	E. W. Myers		290.0
1900. Sept. 7	Middle Saluda River.	1 mile above mouth	N. C. Curtis	11.75	68.0
Oct. 13	do	do	do		55.0
1901. May 2	do	do	E. W. Myers	10.3	181.0
1900. Sept. 7	North Saluda River.	Iron bridge at Marietta	N. C. Curtis	14.7	58.2
Oct. 13	do	do	do	14.17	80.0
1901. May 3	do	do	E. W. Myers	13.5	163.0
1900. Sept. 6	do	Bridge on Lima-Cleveland Mill road.	N. C. Curtis	12.9	56.1
Do	do	2 miles below Humphries's store.	do	14.2	26.1
Do	Fall Creek	Bridge on road to Lima	do		[a] 15.0

[a] Estimated.

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

BROAD RIVER.

PHYSICAL FEATURES.

Broad River rises on the eastern slope of the Blue Ridge, in McDowell County, N. C., between the Swannanoa and the Edmondson mountains. It flows in a southwesterly direction through Hickory Nut Gap (see Pl. XXXIII), until it is joined by Green River, when it bends to the east and maintains that course for about 20 miles. After it is joined by the First Broad it turns abruptly to the south and crosses the North Carolina boundary line near Shelby. The river and its tributaries were examined as far down as Dellinger, S. C., about 1 mile from the State boundary line. Its drainage area in North Carolina includes portions of Henderson, Polk, Rutherford, McDowell, and Cleveland counties, and aggregates 1,400 square miles. Its total drainage area is 4,950 square miles.

Three important branch streams contribute their waters to those of Broad River, two entering from the north, called First Broad and Second Broad, and the other entering from the west and known as Green River. These streams drain an area of the Blue Ridge and adjacent ridges extending to the State boundary line in Henderson County to and including the south side of the South Mountains in Rutherford and Cleveland counties. Pool Creek, a small branch from the south, discharging 6 or 8 cubic feet per second, is interesting on account of the pools which have been formed through the action of the water. There are three of these pools, each resembling a huge auger hole 6 feet in diameter. No definite information was obtainable as to their depths. Buffalo Creek, a small stream rising on the east side of the Bald Mountains and entering Broad River from the north, has a wide flood plain near its mouth and an average rise of 6 feet. Just above Ayr it is said to have a fall of 30 feet. This stream was not visited.

After leaving Batcave, where it is joined by Hickory Nut Creek (a typical headwater tributary shown in Pl. XXXIV), Broad River flows for 6 miles through a gorge which is justly famous for the grandeur of its scenery and the number of interesting natural curiosities. The mountains rise abruptly on either side to a height of 200 feet above the stream bed, and for about three-fourths of the way up are clothed with a thick forest growth. The upper side of each slope is guarded by an escarpment of granite absolutely bare of all verdure. This wall of rock varies in height from 200 to 1,000 feet. On the northeast corner of Sugarloaf Mountain and overlooking the gorge is a perpendicular mass of rock called Chimney Rock, which is detached from the face of the mountain and stands a massive silhouette against the sky. Its greatest height is 213 feet, its diameter at the summit 60

feet. The top of the rock is reached by a wooden stairway. A half mile directly west of Chimney Rock are the falls of Fall Creek, which are said to have a sheer drop of several hundred feet, but the quantity of water is insufficient for water power. On the left bank of the river is a mountain known as Old Rumbling Bald.

The region possesses a great variety of scenic and agricultural features. The soil is generally loose and porous. The headwaters of Broad and Green rivers rise among the high peaks of the Blue Ridge, and after winding their way through gaps and gorges finally emerge and flow through a region of low, rolling hills. There is very little bottom land along any of the larger tributaries. The only extensive stretches observed were along the lower portions of Whiteoak Creek and Cove Creek. The entire region is very healthy. The country east of the Blue Ridge, including the watershed and the drainage basin of Broad and Green rivers, is fair for farming purposes, though the soil is not especially rich. The chief crops in this section appear to be corn and wheat.

RAINFALL.

The rainfall in the basin of Broad River is approximately 51 inches, distributed throughout the year as follows: Spring, 13 inches; summer, 13 inches; autumn, 10 inches; and winter, 15 inches. The rainfall in the region above the headwaters is, however, probably much greater than this. The bed of the stream is of rock, clay, sand, or gravel, but in many places the banks are low and the bottoms are overflowed during freshets.

FORESTS.

The timbered areas are comparatively small. Very little clearing has been done around the headwaters of either Broad River or Green River. The drainage basins of the Broad proper, the First Broad, and the Second Broad contain little valuable timber. For 2 miles above Batcave the land has been considerably cleared for farming, corn being the chief crop. The upper watershed of Reedy Patch Creek has been entirely cleared, and extensive clearing has been done around the heads of Cove, Maple, and Mountain creeks.

MINERALS.

The mineral wealth of the Broad River region is considerable. Deposits of gold are found about the headwaters of the First Broad, the Second Broad, and Silver and Muddy creeks, and these have been worked in a crude way since 1830. Several mines are also being worked on the flanks of the South Mountains, the ore being a

HICKORY NUT GAP FROM CHIMNEY ROCK, NORTH CAROLINA.

HICKORY NUT CREEK, NORTH CAROLINA.

very good grade of sulphuret. Here the famous Bechtler dollar was formerly coined. Monazite is extensively mined and shipped to the North and to foreign countries. Copper, corundum, and tin are among the minerals obtained.

DISCHARGE MEASUREMENTS.

During the investigation two gaging stations were established on Broad River, one at Dellinger, S. C., and the other near Alston, S. C., and measurements were made at these stations and at other places on the main river, as shown in the following table. Measurements of the tributary streams are given in the table on page 143.

Discharge measurements of Broad River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-ft.*
Feb. 26	Near Alston, S. C	E. W. Myers	5.40	8,913.0
Apr. 18	do	do	6.28	
Apr. 20	do	do	13.60	44,456.0
May 22	do	do	3.40	4,406.0
July 5	do	do	4.25	5,962.0
Aug. 17	do	do	2.80	2,840.0
1901.				
May 7	Near Blacksburg, S. C	do	2.50	2,418.0
1900.				
Aug. 30	At Dellinger, S. C	do	0.80	1,430.0
Aug. 28	Ford 1 mile above mouth of Second Broad River, North Carolina.	H. A. Pressey	5.95	649.0
Aug. 25	McClure's bridge, North Carolina	N. C. Curtis	23.43	220.0
Oct. 18	do	do	22.67	434.0
1901.				
Aug. 9	do	do	20.8	683.5
1900.				
Aug. 22	Near mouth of Buffalo Creek, North Carolina.	do	15.2	57.1
Oct. 6	do	do	14.59	145.4
1901.				
Aug. 10	Near Chimney Rock, N. C	do	14.1	247.6
1900.				
Aug. 21	Bridge at Batcave, N. C	do		50.1
Do	do	do	10.15	48.0
Oct. 6	do	do	10.45	62.4

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of all the measurements in the above table except those made near Alston and at Dellinger, where bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In the latter case, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

The average annual fluctuation of the river at its mouth and near Buffalo Creek is 10 feet; at Batcave it is 8 feet.

WATER POWERS.

Broad River rises at an elevation of 3,100 feet. The elevation at the junction of Broad and Green rivers is about 780 feet. The total length of this portion of the stream is about 40 miles and the difference in elevation 2,320 feet, making the average fall per mile 58 feet. The average fall per mile from its head to its junction with Hickory Nut Creek, at Batcave, is 125 feet. From Batcave to a half mile below the mouth of Pool Creek the fall is also 125 feet per mile, but from that point to the mouth of Green River the fall is only 8 feet to the mile. As far down as Batcave the stream has a flood plain of about 75 yards average width, with no very steep slopes on either side. Hickory Nut Creek, a small stream entering the river just above the mouth of Reedy Patch Creek, has an average fall of 175 feet per mile, and the latter stream a fall of 150 feet per mile.

The water power of the upper section of the river is excellent and has been very little developed. Rock ledges are numerous, and falls of 8 feet in 100 feet frequently occur. The only obstacle is the absence of good building sites. There are three mills between Batcave and Pool Creek, each having a working head of about 10 feet.

The distance between Poors Ford and Dellinger is 25 miles. The water powers, descending the stream, are, briefly, as follows: (1) Big Island Ford Shoals, 1½ miles below Poors Ford, having a vertical fall of 3 feet and a slope of probably 6 or 7 feet in 400 yards, with good rock bottom and natural abutments; (2) Durham Shoals, 6 miles below the mouth of Second Broad River, with a vertical fall of 7 feet, which could be increased to 12 feet at the wheel, and with excellent foundations for a dam and building; (3) Palmers Shoals, 1 mile below the mouth of First Broad River, with a fall of about 18 feet in a half mile (the south bank at these shoals is nearly level, but the rock cliff juts out prominently on the north bank); and (4) Hopper and Blanton shoals, where the river makes a horseshoe bend and the difference in elevation across the neck is said to be 30 feet, the short shoal on the lower side of the neck being known as the Hopper Shoal and the one on the upper side as the Blanton Shoal. The latter power could be developed by piercing the neck of the tunnel and damming the water at the Blanton Shoal.

TRIBUTARIES OF BROAD RIVER.

DISCHARGE MEASUREMENTS.

During the investigation the following measurements were made of the principal tributaries of Broad River, in order upstream:

Discharge measurements of tributaries of Broad River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-ft.*
1901.					
May 24	Enoree River	Greenville, S. C	N. C. Curtis	7.7	160.0
Do	Tiger River	14 miles east of Greenville	do	19.5	174.0
May 25	Pacolet River	Clifton, S. C	do	13.1	900.0
1900.					
Aug. 30	First Broad River	Near mouth	do	17.7	285.3
Oct. 10	do	do	do	16.2	266.4
Aug. 23	Puzzle Creek	do	do	6.70	10.0
Aug. 24	Robersons Creek	At mouth	do	-------	24.0
Aug. 23	Hollins Creek	do	do	5.8	14.3
Do	Cathey Creek	do	do	3.35	42.0
Aug. 24	Cane Creek	1 mile above mouth	do	5.43	17.0
Do	Second Broad River.	Bridge on Rutherfordton-Morganton road.	do	7.35	55.0
Oct. 4	do	do	do	7.00	64.0
1901.					
Aug. 13	do	Iron bridge near Bostic Station	do	23.45	273.3
1900.					
Aug. 23	do	1½ miles east of Forest City	do	20.8	153.3
Oct. 5	do	do	do	20.32	188.3
Aug. 31	Whitecoak Creek	One-half mile above mouth	do	4.65	64.0
Sept. 3	Cove Creek	Near mouth	do	5.40	19.2
Do	Green River	Near Saluda, on Howard Gap road	do	17.7	74.1
Aug. 25	do	Cox's bridge	do	22.9	299.0
Oct. 8	do	do	do	22.6	255.4
1901.					
Aug. 9	do	do	do	21.0	833.2
Aug. 25	Maple Creek	Near mouth	do	7.70	8.4
Do	Mountain Creek	do	do	6.83	55.3
Oct. 8	do	do	do	6.48	70.2
Aug. 22	Cove Creek	Bridge at Rutherfordton road	do	18.65	69.3
Oct. 6	do	do	do	18.16	86.0
Aug. 23	Buffalo Creek	15 yards below main ford	do	4.10	17.0
Aug. 21	Reedy Patch Creek.	At mouth	do	5.75	13.0
Do	Hickory Nut Creek.	do	do	4.80	15.2

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

Brief descriptions of the drainage basins and water powers of the three largest tributaries are given on the following pages.

FIRST BROAD RIVER.

This tributary rises on the southern slopes of the South Mountains, in the northern part of Cleveland and Rutherford counties, N. C., and flowing south joins Broad River about 8 miles south of Shelby, N. C. It drains an area of 302 square miles. The fall between the

crossing of the railroad from Shelby to Rutherfordton and the mouth of the stream is about 105 feet, or at the rate of 8 feet per mile. The width of the stream at its mouth is about 90 feet.

The water powers on the First Broad are as follows: Ten miles north of Shelby and 3 miles north of the Double Shoals, where is located Cleveland cotton mill No. 2, which contains 4,224 spindles and is run by water power exclusively, a fall of 13 feet being utilized. At the Double Shoals there is a cotton factory which contains 2,000 spindles run by water power. The dam is 9 feet high, giving a total fall of 15 feet. Three miles southwest of Shelby are the Lauraglen cotton mills, containing 3,500 spindles operated entirely by water power. The dam is 14 feet high and 200 feet long, the fall of water at the mill 15 feet. Chambers's gristmill, still farther downstream, utilizes a fall of 9 feet, though more is available—the stream at this point will probably afford 7 or 8 horsepower per foot of fall in the low season of dry years. Stices's Shoal, about 4 miles from the mouth of the river, has a natural fall of 6 feet in a distance of 80 feet over a smooth rock bed, with considerable fall below. By the construction of a dam across the upper part of this shoal the fall could be increased still more. The Buck McSwain Shoal is about 1 mile above the mouth of the river, and has a natural fall of 3 feet in 150 yards.

SECOND BROAD RIVER.

This stream rises on the southern slopes of the South Mountains, in McDowell County, N. C., about 10 miles directly south of Marion. It flows in a southerly direction, meeting Broad River about 8 miles below the confluence of Broad and Green rivers. It drains an area of 193 square miles, and has a total length of about 50 miles. The elevation of its headwaters is 1,500 feet, of its mouth about 700 feet, giving an average fall per mile of 16 feet.

Comparatively little clearing has been done around the headwaters of either Second Broad River or Cove Creek, a tributary of Broad River which rises near the Second Broad and drains a considerable portion of the southern slopes of the South Mountains. The proportion of cleared land here is estimated to be about 10 per cent of the entire area. Lower down, however, along Cathey and Robersons creeks, the amount of cleared land is much greater, probably 50 or 60 per cent of the whole. After leaving the South Mountains the river flows through a region of low, rolling foothills. The timbered areas are thinly covered, the trees being chiefly pines and scrub oaks. The soil is rather compact, of a light-yellow color, and not particularly rich, and permits fairly good roads to be constructed without much difficulty.

Rutherfordton, the county seat of Rutherford County, about 6 miles west of the Second Broad, is on the western boundary of the cotton belt. The farming lands of Cleveland County and the eastern

half of Rutherford County are mainly devoted to the production of cotton. Some sorghum cane also is raised, and the farmers usually make enough molasses for their own consumption. As the headwaters of the Second Broad and Cove Creek are approached the soil increases in fertility. The Cove Creek Bottoms are especially adapted to the production of corn, and along the slopes of the South Mountains tobacco is easily grown. The climate of the region is salubrious, and very little sickness prevails at any season of the year.

The waters of the First Broad and the Second Broad are never clear, even after protracted droughts, but are a sort of light-brown or yellow-ochre color. This is due to the character of the soil and to the extensive clearing which the watersheds have undergone. The beds of both streams are sandy except where rock shoals occur.

There are four cotton mills in operation in the Second Broad River region. The motive power of two of them is supplied by steam and of the other two by water. One of the steam mills is at Rutherfordton and the other at Forest City. The two water-power mills are known as Henrietta No. 1 and Henrietta No. 2. The former is 6 miles above the mouth of the river, at High Shoals, the latter about 7 miles above the mouth, at Caroleen. Both factories are connected with the Seaboard Air Line Railroad by branch lines. Henrietta mill No. 2 occupies the shoals formerly known as Harrells Shoals and Old Burnt Factory Shoals. A masonry dam about 24 feet in height gives a fall at the wheel of 29 feet. The natural fall of the shoals is 18 feet. The mill contains 35,000 spindles and 1,000 looms. At Henrietta mill No. 1 the natural fall is 23 feet, but a stone dam, slightly curving upstream, 17.8 feet high, gives a fall at the wheel of 32 feet. This dam is 200 feet long. The race is 300 feet long, 35 feet wide, and 10 feet deep. The mill operates 25,000 spindles and 1,000 looms. Both factories have auxiliary steam plants, and seem to have been extremely successful and profitable to their owners. The cotton used is raised in the immediate vicinity and hauled to the mills on wagons. About 2 miles from the mouth of the river the stream makes a long curve, the hillsides closing in very close to either bank. A site has been surveyed here for a large mill, and land has been cleared and construction begun. The natural fall between this site and Henrietta mill No. 1 is about 40 feet. A dam 23 feet high is to be built. No race is to be constructed, but the wheels are to be located at the dam. The fall below the shoals is abrupt for a short distance, and the waste water will flow off readily. The building site is fairly good. This dam will destroy the water power of Tumbling Shoals, 3 miles above the mouth of the river.

GREEN RIVER.

Green River rises in Henderson County, near the Transylvania County boundary line, on the northwestern slopes of the Saluda Moun-

tains. The elevation of its headwaters is 2,900 feet, of its mouth 780 feet, the difference in elevation being 2,120 feet. The total length of the river is about 45 miles, making the average fall per mile about 47 feet. The distance from its head to the point where it emerges from the Blue Ridge is 23 miles, and the difference in elevation between the two points 1,800 feet, making the average fall per mile in that section 78 feet. The length of the remaining section is 22 miles and the difference in elevation 320 feet, making the average fall per mile only 15 feet. The drainage area is 198 square miles.

Along the upper portion of the river the mountain slopes shut in very close, and the timber on the watersheds is practically untouched. Consequently the flow of the stream is constant and the water always clear and cold. The scenery up Green River Cove and around Saluda while beautiful is not remarkably grand. The two most conspicuous mountain peaks are Whiteoak and Tryon. The latter has an elevation of about 3,200 feet.

Between Zirconia and the mouth of Cove Creek the river flows in a narrow gorge. The water power of this section is excellent, but building sites are scarce. The two water powers which are considered among the best on the stream were visited. The first of these, the Pot Shoals, is about 2 miles below the Southern Railway bridge. The fall consists of a drop of 8 feet and a total fall of possibly 30 feet in 100 feet. There is a fairly good site for a building here and excellent facilities for constructing a dam. The next power is at The Narrows, about 4 miles below the Pot Shoals. Here the stream is forced to pass through a narrow and rocky channel 7 feet wide and 50 feet long. The fall is about 10 feet in 100 feet. Building facilities are poor. Another power on the river, known as the falls of Green River, is not so well located as are the Pot Shoals. Here "the fall is about 30 feet in 100 feet, preceded by rapids for three-eighths of a mile, making a total fall of 45 feet. The banks are rocky and very steep, so that building facilities are not good." On the whole, the water powers of Green River are better than those of the Upper Broad, but they are not so accessible, and the building sites are poor. The average annual fluctuation of the river at its mouth is 11 feet; near Saluda it is 9 feet.

The healthfulness of the Green River region is unexcelled. Saluda and Tryon, situated on the Asheville and Spartanburg division of the Southern Railway, are popular summer and winter resorts.

Great expectations are entertained of the deposits of zircon in the valley of Green River.

The side streams flowing into Green River are mostly short, but have heavy falls. Whiteoak Creek is the only tributary of importance. Its fall, however, is small, but it has a very wide flood plain. The bottom land is well cultivated, mostly in corn. The soil is loamy and rich. The average fall is about 12 feet to the mile; the average annual fluctuation 10 feet.

FALLS ON UPPER CATAWBA RIVER, NORTH CAROLINA.

CATAWBA RIVER.

PHYSICAL FEATURES.

This river rises near the Buncombe and McDowell county line in North Carolina, and flows almost due east through McDowell and Burke counties and between Alexander and Catawba counties, where it turns to the south and finally enters South Carolina near the Mecklenburg-Gaston-York county line. After a course of about 160 miles in South Carolina it joins the Congaree to form the Santee. Below the mouth of Big Wateree Creek the river is known as Wateree River. Its drainage area in North Carolina is 3,085 square miles. Its total drainage area is 5,225 square miles.

The Catawba receives its headwaters from the southeastern slopes of the Blue Ridge, the main stream rising at the junction of the latter mountains with a spur known as the Edmondson Mountains. At Oldfort the waters of Mill Creek, with its branch, Jarrett Creek, are added to the Catawba, forming a river of considerable size. The drainage basins of these streams are decidedly mountainous, with steep, wooded slopes. The streams are swift mountain torrents, with large falls and great fluctuations of discharge. The flow at times of low water, however, is fairly large. On Catawba River above Oldfort there are precipices many feet in height, over which the river plunges in its descent toward the Piedmont Plain. (See Pl. XXXV.) In the first 6 miles of its course the river falls 1,500 feet. Below Oldfort the character of the drainage basin changes, becoming very like that of the Yadkin, described on pages 158 to 164. The valley broadens out, especially on the south side of the river, the land immediately contiguous to the stream being flat or gently rolling. The Blue Ridge is not far distant, however, extending to the northeast, with frequent ridges projecting toward the Catawba, between which flow the numerous northern branches of the stream. The tributaries from the north are Curtis, Crib, Clear, and Buck creeks, North Fork, Paddy Creek, Linville River, Cane Creek, Upper Creek, John River, and Lower Creek. These streams for the most part receive their waters from either the Blue Ridge or the Linville mountains, and in their upper courses run between parallel ridges with steep slopes heavily wooded. In their lower courses they reach the Piedmont Plain, where the fall becomes less and their valleys more open, being generally cultivated to some extent.

The river receives several tributaries from the south between the source of the stream and Morganton. The chief of these are Crooked Creek, Muddy Creek, and Silver Creek, meandering, comparatively slow-flowing streams, with a large part of their drainage areas under cultivation.

The reconnaissance of the drainage basin of Catawba River extended only from its headwaters to Morganton, N. C., that being the portion of greatest interest in connection with the studies of the proposed Southern Appalachian Park. Below Morganton the river receives a number of large tributaries and has many water powers in its course across the Piedmont Plain, but they were not visited.

RAINFALL.

The average rainfall in the basin of the Catawba is about 50 inches, distributed as follows: Spring, 12 inches; summer, 14 inches; autumn, 10 inches; and winter, 14 inches. Toward the upper part of the stream, however, the rainfall in winter increases, and is probably greater than in summer.

FORESTS.

The region of the headwaters of the Catawba and its chief branches, which flow from the steep slopes of the Blue Ridge, is heavily forested. At the foot of the mountains the timber consists of beech, poplar, linn, oak, and ash, changing to pines as the slopes are ascended, and near the summits to balsam fir. In the broad valley of the main stream a large part of the land has been cleared and is now used for agricultural purposes. The soil is deep and fertile, the top soil being largely flood deposits of the river. When the forests are cleared from the bases of the steeper mountain slopes considerable difficulty is experienced from the washing away of the top soil, leaving only the barren subsoil or clay beneath. This wash is often so extensive as to completely destroy large areas of land. Pl. XXXVI shows the effect of deforesting areas which can not properly be protected from this agency.

The banks of the Catawba are subject to overflow during the highest floods, and great damage is often caused. It is not uncommon for a fine stretch of farming land to be completely ruined in a single day by the high waters washing away the soil down to the bottom clays or gravels. (See Pl. XXXVII, *A*.) It has been estimated that in the drainage basin of the Catawba a single flood has caused damage to the extent of a million dollars. (See Pl. XXXVII, *B*.) That these floods are checked to some extent by the forests there can be no doubt; and in the absence of other regulators, such as lakes or marshes, the forests on the mountain sides form the only protection that the people dwelling in the valleys below have from the violence of flood waters.

DISCHARGE MEASUREMENTS.

During the investigation temporary gaging stations were established on Catawba River near Morganton, on John River near Morganton, and on Linville River near Bridgewater. For several years the

A.

B.

VIEWS SHOWING HILLSIDE WASH IN VALLEY OF CATAWBA RIVER.

A. VIEW SHOWING REMOVAL OF SOIL IN VALLEY BY FLOODS.

B. VIEW IN VALLEY OF CATAWBA RIVER, SHOWING DESTRUCTION BY FLOODS.

Survey has maintained two stations on the Catawba River—one at Catawba, N. C., and the other at Rockhill, S. C.—the results of which have been published in the annual reports. The results of all measurements made on the river during the investigation are contained in the following table; the results of measurements on the tributaries in the table on pages 151 and 152.

Discharge measurements of Catawba River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-feet.*
Feb. 21	Rockhill, S. C.	E. W. Myers	2.63	3,803
Feb. 22	do	do	5.28	16,791
Apr. 13	do	do	2.75	4,706
Apr. 21	do	do	9.07	31,610
May 21	do	do	2.42	3,703
July 4	do	do	2.86	5,623
Aug. 16	do	do	1.70	1,936
Oct. 26	do	do	3.30	8,843
1901.				
Apr. 4	do	do	9.80	33,150
Apr. 23	do	do	4.65	10,314
May 23	do	do	*24.15	150,783
July 20	do	do	2.00	3,822
1900.				
July 3	Catawba, N. C.	do	3.45	3,372
Aug. 14	do	do	2.10	914
Nov. 7	do	do	2.95	2,083
Dec. 18	do	do	2.59	2,139
1901.				
Mar. 29	do	N. C. Curtis	5.83	5,640
Apr. 27	do	E. W. Myers	4.37	4,354
July 25	do	do	2.95	2,805
1900.				
June 13	Near Morganton, N. C.		1.33	1,393
June 18	do		2.50	4,030
July 6	do		1.30	1,164
Aug. 8	do		0.60	558
Sept. 24	do		0.50	525
Nov. 7	do		1.50	1,374
June 28	Oldfort, N. C.	H. A. Pressey	10.10	53
Aug. 20	do	N. C. Curtis	12.70	11
Sept. 20	do	do	12.78	12

*Greatest flood ever known on river.

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of all the measurements in the above table except those made at Oldfort, where a bench mark was established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In the latter case, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

The following table, computed by E. W. Myers, shows the comparative minimum flows of Catawba River at the Catawba and Rockhill stations, which are about 60 miles apart, for the years 1895 to 1899. The drainage area at Catawba is 1,535 square miles and at Rockhill 2,987 square miles. Comparing this table with a similar one for Yadkin River, published in Water-Supply Paper No. 36, page 119, it will be seen that the run-off per square mile does not vary more than would be expected. The Catawba station was established in 1896, the Rockhill station in 1895.

Table showing comparative minimum flows of Catawba River at gaging stations at Catawba, N. C., and at Rockhill, S. C.

Year.	Driest month.		Mean flow for driest month.		Mean flow per square mile for driest month.		Minimum flow for year.		Minimum flow per square mile for the year.	
	Rockhill.	Catawba.	Rockhill.	Catawba.	Rockhill.	Catawba.	Rockhill.	Catawba.	Rockhill.	Catawba.
			Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
1895	Sept[a]	.....	1,318	.....	0.441	.....	1,300	.....	0.435	.....
1896	Aug	Oct	1,604	865	.54	0.56	[b]1,330	770	.445	0.501
1897	Sept	Sept	1,817	1,017	.61	.66	[c]1,575	[d]850	.526	.553
1898	June	June	2,091	1,069	.70	.69	1,600	910	.535	.592
1899	Nov	Nov	2,492	1,340	.835	.873	2,300	1,220	.770	.793

[a] Seven days' record.
[b] Also in July, August, and September.
[c] Minimum occurred in January. September minimum was 1,700 second-feet, or 0.569 second-foot per square mile.
[d] Minimum in October. September minimum 900 second-feet, or 0.579 second-foot per square mile.

WATER POWERS.

Between Morganton and the mouth of Mill Creek, a distance of 50 miles, there are 197 shoals with an average fall of about 2 feet. In McDowell County the fall of the river is very great, there being in one or two cases vertical drops of 100 feet, but the channel is so narrow that the power is not of great value for development. Rock Ford Shoal, at Morganton, has a natural fall of 9½ feet in a distance of about 1,500 feet.

Although the investigation embraced only the portion of the drainage basin above Morganton, as some of the chief water powers of the river are below that place they will be mentioned in this connection. Briefly described, they are as follows:

Devil Shoal has a fall of 14 feet in a distance of 1 mile, and is well located for improvement. Horseford Shoal, 3 miles north of Hickory, has a fall of 31 feet in 2.9 miles; the power is utilized to only a limited extent. The Great Fall Shoals have a fall of 14.8 feet in a distance of 1 mile. Canoe Landing Shoal, about 2 miles above the mouth of Lower Little River, has a fall of 8.9 feet in a distance of 1.87 miles. The Lower Little River Shoals are between the upper end of Druin Island and the lower end of Three-Cornered Island, with a fall of 9.7 feet in a distance of 1.16 miles. Lookout Shoal, about 6 miles above Catawba Station, has the greatest fall of any shoal on the river in North Carolina, the descent being 54.25 feet in a distance of 3.2 miles. About 30 feet of this fall is said to occur in a distance of three-fourths of a mile. The Buffalo Shoals have a fall of 11.4 feet in a little more than a half mile; they are a short distance below the Western North Carolina Railroad crossing. Long Island Shoal, about 7 miles southeast of Catawba Station, has been improved and a cotton factory constructed to utilize the power. Monbo Shoal is utilized by a cotton mill. Beatties Ford Shoal has a fall of 13 feet in 2.38 miles, and

Cowan Ford Shoal a fall of 27 feet in a distance of 4.17 miles. Mountain Island Shoal is utilized to a small extent by a cotton factory containing 6,300 spindles and using a fall of 22.5 feet. Tuckasegee Shoal, about 9 miles above the State line, has a natural fall of 11 feet in a distance of 1 mile, and is utilized by a cotton mill of 6,000 spindles. Near the State line there are several shoals with falls of from 3 to 5 feet, some of which have been used to a limited extent, but considerable difficulty has been experienced from high water.

TRIBUTARIES OF CATAWBA RIVER.

DISCHARGE MEASUREMENTS.

During the investigation the following measurements were made of the important tributaries of the Catawba above Morganton, N. C., in order downstream:

Discharge measurements of tributaries of Catawba River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
June 28	Mill Creek	Oldfort	H. A. Pressey	3.85	85.0
Aug. 20	do	do	N. C. Curtis	6.73	27.0
Sept. 20	do	do	do		13.0
June 28	Jarrett Creek	Near Oldfort	H. A. Pressey		17.0
Do	Curtis Creek	200 feet above ford of Oldfort road.	do		82.11
Aug. 20	do	do	N. C. Curtis		16.50
June 28	Crib Creek	Near ford of main road	H. A. Pressey	4.9	28.03
Aug. 28	do	do	N. C. Curtis		10.0
June 28	Clear Creek	200 feet above ford of main road.	H. A. Pressey		25.25
Aug. 28	do	do	N. C. Curtis		12.0
June 14	Buck Creek	¼ mile above mouth, at main ford.	H. A. Pressey		51.91
Aug. 20	do	do	N. C. Curtis	5.35	41.4
July 3	North Fork of Catawba River.	First ford above mouth	H. A. Pressey		240.2
Aug. 18	do	do	N. C. Curtis		67.3
Sept. 21	do	do	do	3.18	61.69
June 15	Turkey Cove Creek	Just above second ford	L. V. Branch	5.75	21.48
June 26	do	do	do	5.30	164.8
June 14	Muddy Creek	Bridgewater	H. A. Pressey	5.80	161.9
June 16	do	do	L. V. Branch	4.1	618.0
July 10	do	do	do	6.0	119.2
Aug. 17	do	do	N. C. Curtis	6.43	98.6
Sept. 21	do	do	do	6.34	101.7
June 14	Paddy Creek	Near Bridgewater	H. A. Pressey	11.3	19.78
June 16	do	do	L. V. Branch	5.4	203.67
July 10	do	do	do	11.55	11.5
Aug. 17	do	do	N. C. Curtis	12.35	7.0
June 21	Linville River	Linville	H. A. Pressey	14.83	21.0
June 24	do	do	do	14.23	90.22
June 14	do	Near Bridgewater		9.92	104.0
July 3	do	do		9.54	216.0
July 10	do	do		9.90	116.0
Aug. 17	do	do		10.15	78.0
Sept 21	do	do		9.8	55.0
June 14	Cane Creek	Lowest ford of main Morganton road.	H. A. Pressey	5.72	18.58
June 18	do	do	L. V. Branch	5.85	28.45
Aug. 17	do	do	N. C. Curtis	6.3	7.2
June 14	Silver Creek	Near Morganton	L. V. Branch	6.84	124.0
Aug. 10	do	do	N. C. Curtis	8.30	48.4
Sept. 24	do	do	do	8.20	56.0
1901.					
June 14	do	do	E. W. Myers	13.08	995.0

Discharge measurements of tributaries of Catawba River—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
June 13	Upper Creek	¼ mile above mouth	N. C. Curtis	2.2	182.4
July 6	do	do	L. V. Branch	2.3	50.0
Aug. 8	do	do	N. C. Curtis		85.05
Sept. 24	do	do	do		60.0
June 20	do	Ford at Henderson's mill	H. A. Pressey	12.9	20.42
Do	do	Upper Creek Falls	do		27.0
Do	Steel Creek	Footbridge 100 yards above mouth.	do	3.20	100.21
Sept. 25	John River	Collettsville	N. C. Curtis	4.77	40.0
Nov. 6	do	do	do	4.47	135.0
June 13	do	Near Morganton		2.64	465.0
June 19	do	do		3.50	1,202.0
July 6	do	do		2.63	511.0
Aug. 8	do	do		1.90	135.0
Sept. 24	do	do		1.90	148.0
Nov. 7	do	do		2.32	367.0
Sept. 25	Mulberry Creek	At mouth	N. C. Curtis	7.85	17.0
Nov. 6	do	do	do	7.95	39.0
Do	Wilson Creek	do	do	0.75	208.0
June 13	Lower Creek	2 miles above mouth	E. W. Myers	14.58	209.0
July 6	do	do	L. V. Branch		132.0
Aug. 8	do	do	N. C. Curtis		69.0
Sept. 24	do	do	do	15.38	56.0

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in above table of John River near Morganton and of Linville River near Bridgewater. In making all of the other measurements, however, in each case a bench mark was established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In these cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

The principal tributary drainage basins and water powers are briefly described on the following pages.

CENTER, CRIB, AND CLEAR CREEKS.

Of the tributaries from the north, Center, Crib, and Clear creeks have drainage areas of a similar character. There is considerable fall near their sources, which gradually becomes less as the streams are descended, the valleys broadening out and being partially cultivated. About three-fourths of the drainage areas are forest-covered. The streams are too small for extensive water-power development, but two small gristmills have been built on Crib Creek. The low-water flow of the stream is so small, however, that the mill can not be run during the dry season.

BUCK CREEK.

This creek rises in Buck Creek Gap, and has a drainage basin similar to the creeks just described, though much larger. The fall is very great along its upper course. Six miles from its mouth are the falls of Buck Creek, with a vertical drop of 12 feet. A rough and rocky highway, leading from Marion through Yancey County, follows the stream throughout its course. The scenery near the gap is very fine. Two mills have been constructed, and are run during a part of the year. Near the mouth of the creek there are some

good farms. About a quarter of a mile above the mouth the Marion-Oldfort road crosses the creek. Here measurements were made of the discharge (see table on page 151).

NORTH FORK OF CATAWBA RIVER.

This stream enters the Catawba near Marion. At its headwaters it is a mountain stream with very heavy fall, draining the narrow valley between the Blue Ridge and the Linville mountains. The mountain slopes are covered with a valuable growth of timber, practically no cutting having been done on them. About 7 miles downstream the valley broadens slightly and furnishes a very fertile soil excellent for agricultural purposes. This valley land has been cleared and is now largely in grain or grass. About three-fourths of the drainage area is still in forest. Two small combined gristmills and sawmills have been built on the stream, with falls of 6 and 8 feet. Turkey Cove Creek, a branch of the North Fork, is a mountain stream of considerable fall, with wooded slopes. The total drainage area of the North Fork is 835 square miles.

PADDY CREEK.

This creek has the same general characteristics as the other northern tributaries of the Catawba in the region. Its headwaters are on the steep slopes of the Linville Mountains, and its lower course is across the Catawba Valley. Its watershed is long and narrow, being close to Linville River on one side and flowing nearly parallel to the Catawba on the other.

LINVILLE RIVER.

This river is formed by a number of small streams which head on Grandfather and Sugar mountains and in Linville Gap. The sources of most of the streams are large springs, which are numerous throughout the region, furnishing perfectly clear and chemically pure water. Grandfather Mountain has an elevation of 5,964 feet; the heads of most of the streams rising upon its slopes are at an elevation of 5,000 feet. The elevation of Sugar Mountain is 5,289 feet, while Linville Gap, between these two high peaks, has an elevation of 4,097 feet. Four miles south of Grandfather Mountain is Grandmother Mountain, elevation 4,686 feet, upon which rises Grandmother Creek, which flows into Linville River 1 mile below the village of Linville.

The mountain slopes are steep and rocky, the small streams falling in a series of cascades. The virgin growth of timber is still on the mountain sides and extends to the summits, practically no cutting having been done. Three miles below Linville, at Pineola, there is a healthy growth of white pine, but from Linville upstream the river is above the white-pine belt, the growth changing to spruce, chestnut,

white and red oak, poplar, linn, ash, buckeye, birch, beech, cherry, and, on the highest elevations, balsam fir. The temperature is usually low, frosts having been known to occur in each month of the year.

Below Grandmother Creek the river has no tributaries of any size. From Grandfather Mountain to Linville Falls its valley is narrow, the land on both banks rising abruptly to the mountain summits, permitting only short tributaries and a narrow drainage area. Linville, a village of about thirteen houses and a summer hotel, is between the river and Grandmother Creek, on a comparatively flat area, and Pineola, 3 miles below, a village built up largely during 1900, occupies another flat section.

The falls of the Linville, located near the Mitchell-Caldwell-McDowell County line, have an aggregate fall of 90 feet in four clear leaps. The first fall is 50 feet upstream from the main fall, and is a vertical drop of 15 feet. There are then three drops in quick succession of 25, 10, and 40 feet, respectively. The water at the last drop (see Pl. XXXVIII) falls in one sheet into a still pool, from which it flows through a narrow gorge 10 miles long between Gingercake Mountain, Hawks Bill, Table Rock, and Shortoff Mountain on the east and the Linville Mountains on the west. The walls of this gorge are precipitous, in many places almost vertical, and rise to heights of from 500 to 2,000 feet. Through it the Linville has no tributaries, receiving only the water which falls on the steep slopes and the flow from the springs on the mountain sides. It may well be considered one of the greatest mountain features of the region. The high and rocky walls are so close to the river that there is no space for highway or railroad. In fact it is with the greatest difficulty that one can make his way through the chasm, jumping from rock to rock, clinging to rocky ledges, and in places where no foothold is offered on either side wading the stream. The scene is grand and inspiring, viewed either from the chasm, where immense vertical rocky cliffs rise on either hand, showing nothing beyond but the blue sky, or from the upper edge of the gorge, where one can look vertically down several hundred feet and see the rapid, sinuous stream cutting its way to the valley below.

At Linville Falls, at the upper end of the chasm, the drainage basin of the main stream and its tributaries has an area of 50 square miles. The next 10 miles of the course of the river is through the gorge. After emerging from the rocky walls of the chasm it flows for 8 or 9 miles as a comparatively quiet stream through Birch Bottom and Catawba Valley, finally joining its waters to Catawba River.

At Linville records of rainfall have been kept by the United States Weather Bureau for nearly eight years. These records show that the annual precipitation is about 46 inches, distributed as follows: Spring, 11.50 inches; summer, 13.50 inches; autumn, 9.50 inches; and winter, 11.50 inches. The climate is pleasant and very healthful, so that

LOWER FALLS OF LINVILLE RIVER, NORTH CAROLINA.

numerous summer visitors take advantage of the excellent hotel accommodations at Linville, at the foot of Grandfather Mountain.

There are opportunities for development of water power on the Linville and its tributaries. On Grandmother Creek the Linville Improvement Company has built a timber-crib dam across the stream near its mouth, to form a fish and ice pond. The dam is 20 feet high, but its height could be increased and a small water-power plant installed. There is another site farther up the creek where a fall of 15 or 20 feet could be developed.

At Linville Falls, on the main stream, at the head of the gorge, considerable power could be developed, though the chasm is so narrow that there would be difficulty in finding space for buildings. From Linville Falls to the point where the river enters the flat plain of the Catawba Valley the fall of the river is large, with frequent drops of 3 or 4 feet. About 2 miles below Linville Falls, near Bynums Bluff, there is a fall of 5 feet, and 1½ miles farther down is what is known as Cascade Rock, where the river falls vertically 12 feet. From the foot of the falls to the Catawba Valley the fall of the river is about 1,800 feet. None of the power in the gorge or at the falls has been developed.

There are several small mills on the river. One mile above Linville there is a small sawmill and gristmill with an 8-foot timber dam, which has sufficient water to run throughout the year. Two miles above Linville Falls, at the mouth of Camp Creek, there is a sawmill and gristmill utilizing an 8-foot fall, and 1 mile above the falls there is a sawmill with a timber dam 10 feet high, a 46-inch turbine being used to run a circular saw. At the Franklin mill, a half mile above the falls, Pine Creek has a 10-foot fall, and power is furnished by overshot wheels and turbines. About 4 miles above the mouth of the river, at Berry's mill, an 11-foot head is utilized with a 4-foot home-made wheel, and 3½ miles lower down, at Pool's mill, a 9-foot fall is utilized for a gristmill run by a 20-inch and a 36-inch wheel. On July 3, 1900, a gage was established at the latter mill, and the miller reads the height of the river every day. Measurements of flow have also been made, the results of which are given in the table on page 151.

In ordinary years the river has a fluctuation of about 8 feet at Pool's mill, though on September 6 and 7, 1898, the water rose 18 feet in forty-eight hours. This is the highest stage known, but in 1882 there was a rise of about 17 feet.

CANE CREEK.

Cane Creek, flowing into the Catawba from the north, drains 16 square miles of comparatively flat and open country, much of which is under cultivation. There is very little fall in this stream. The measurements made are given in the table on page 151.

UPPER CREEK.

This stream, the next important tributary of the Catawba from the north, rises on Jonas Ridge and Cranberry, Cold, and Park mountains, at an elevation of about 4,000 feet. The sides of these mountains are for the most part steep and precipitous and are covered with a dense forest growth. The most common trees are chestnut, oak, white pine, and poplar. Very little of the original timber has been cut, though fires have spread over considerable areas, seriously injuring the forests. As the fires, however, were widely separated, both in time and in area, the drainage basin near the headwaters of the stream is almost entirely forest covered, either with the original timber or with a younger forest growth.

A large part of the regular flow of the creek is made up of effluents from springs, which are numerous on the mountain slopes. To this flow, however, is added the surface drainage from the mountain sides, which in the upper part of the creek reaches the stream quickly, so that during a rain the creek rises rapidly and falls soon after the rain ceases.

Throughout this and the neighboring watersheds will be found shady ravines, with springs breaking forth and adding their waters to other springs until a considerable stream is formed with a comparatively constant flow. The Piedmont Springs, 9 miles from the source of Upper Creek, have been celebrated for thirty years, and formerly many people from the Southern States visited them as a summer resort, being accommodated in a large hotel close at hand. The springs are charged with iron and soda. Though still flowing, they are not now much visited and the hotel has fallen into decay. About 2½ miles from the source of Upper Creek is Cold Water Spring, where a hotel has recently been built to accommodate summer visitors.

The fall of Upper Creek and its tributaries is very great from the headwaters down to Piedmont Springs. The two forks of the creek have a fall of 250 feet per mile to their junction. In the next mile there is a fall of 1,000 feet, largely made up of a series of small falls of from 5 to 10 feet. About one-fourth of a mile below the Cold Spring hotel there is a single fall of 90 feet. On June 20, 1900, the stream was measured a few feet above these falls, and the quantity flowing was found to be 27 second-feet. The low-water flow is probably about two-thirds that amount. The walls here are steep and rocky, with good natural abutments for a dam, though the fall is so great that the storage capacity would not be very large. About three-fourths of a mile above these falls there is a combined shingle mill, sawmill, and gristmill. An 8-foot dam has been built across the stream, giving an 18-foot head on the wheel—a Smith-Morgan turbine. A half mile farther down there is another small sawmill and gristmill. Between the main falls of Upper Creek and the gristmill there is a fall of at least 200 feet in a distance of three-fourths of a mile.

The low-water flow of the creek is quite large, owing to the many springs in its watershed and to its forested basin. From Jonas Ridge down to Joy the drainage area is completely covered with forest from the river bank to the summits of the mountains. The most common trees are chestnut-oak, white pine, and poplar. At Joy there is a small gristmill with a 6-foot timber dam, and a half mile below there is a gristmill and sawmill with a flow of about 8 feet over a timber dam, two 36-inch turbines furnishing the power. There is another gristmill on Upper Creek near the mouth of Irish Creek. From Joy to the mouth of Upper Creek the valley is wider and the hills bordering the watershed are comparatively low and flat, rising on either side about 100 feet above the stream. The hillsides are largely covered with forests, the growth extending to the banks of the creek. There are, however, open cultivated areas through the valley, the chief crops being corn and wheat. It is probable that two-thirds of the total drainage area of Upper Creek is forested.

Below Joy there are two mills—Turner's and Wakefield's. In the next mile there is a fall of about 25 feet, the ordinary high-water rise above the present stage being about 7 feet. Turner's mill is a gristmill and sawmill with a fall of about 8 feet, two 36-inch Smith-Morgan turbines being used. The 7-foot dam backs the water about a quarter of a mile. At lowest stages the water is about 6 inches lower than at the time of measurement, when the discharge was 20.42 second-feet. In 1898 there was unusually high water, the stream rising 16 feet. Three miles below Turner's mill is Caldwell's gristmill, owned by Mrs. W. C. Anderson. There is a fall of 7½ feet here and backwater for 1 mile. There is said to be 14 horsepower available with one Smith-Morgan turbine 20 inches in diameter. At lowest stages the stream at this point falls about 4 inches below the surface elevation at the time of measurement, and at such times it has about one-third less flow. During high-water periods the rise is about 6 feet. The highest water known was about 12 feet above the surface elevation at the time of measurement.

Steel Creek.—This tributary of Upper Creek, which rises on Hawks Bill and neighboring mountains, enters the latter creek near Joy. Its drainage area has the same general characteristics as that of the upper part of Upper Creek, and its fall will average 530 feet per mile for the first 3 miles, 200 feet per mile for the next 2 miles, and 50 feet per mile the rest of the way.

JOHN RIVER.

John River, the largest tributary of the Catawba, adds its water to the latter stream about 3 miles northeast of Morganton. Its drainage area contains 213 square miles and is extremely rough and mountainous in its upper part, the topography becoming gradually more gentle as the river is descended. It receives its headwaters from the many

fine, large springs and the run-off on Grandfather Mountain and the other mountains in the region near Blowing Rock.

This drainage basin, with its fine views, its dense forests, its numerous springs, and its salubrious climate, is one of the most beautiful and delightful parts of the Southern Appalachian region. The many summer guests at the hotels at Blowing Rock and Linville are well repaid for their visit by a day spent on the summit of Grandfather Mountain, from which is obtained a most magnificent view of the great billowy sea of mountains stretching away from it in every direction. A ride over the Yonahlossee road, the finest mountain road in the South, with its frequent glimpses of river valleys and mountain peaks beyond, with its numerous little streams which dash down the mountain sides, cross the road, and leap from rock to rock in their descent to join John River or one of their tributaries far below, is a pleasure to be long remembered.

The main stream and its upper tributaries, chief among which are Mulberry and Wilson creeks, have falls of 2,000 or 3,000 feet in the first few miles of their courses. Vertical falls are frequent, especially on Wilson Creek, and considerable power could be developed. Above Collettsville, at the junction of Mulberry Creek with John River, the drainage area is rough, the valley narrow, and the mountain slopes steep and well timbered. Below the junction the valley widens considerably, and where cleared of trees it presents a splendid farming country. There are great tracts, however, which are still in timber. On the ridge to the west of the river there has been considerable prospecting for gold, and a plan has been considered of constructing a flume to carry water from Wilson Creek across John River for use in hydraulic mining.

LOWER CREEK.

Lower Creek, the next tributary of the Catawba from the north, has a comparatively flat watershed. The fall is not so great as that of the upper branches, and in every way the creek has more the nature of a stream of the Piedmont Plain.

YADKIN RIVER.

PHYSICAL FEATURES.

Yadkin River rises on the eastern slopes of the Blue Ridge, in Caldwell and Watauga counties, near Blowing Rock, N. C. Its course is almost south, until at Patterson it turns to the northeast. It was examined and gagings were made as far down as Ararat River, a large tributary from the north. In this portion of its course it flows through Caldwell and Wilkes counties and between Yadkin and Surry counties.

Beginning at Siloam, where the flood plain of the river is about three-fourths of a mile wide, the bottom land gradually widens as the head of the stream is approached, being in some places nearly 2 miles in width. The flood plain is subject to occasional overflows. Its soil is very deep and fertile, the result of washings from the mountain slopes above. The river basin between Patterson and Siloam varies in width from 5 to 25 miles. The divides which separate it from the basins of the New and the Catawba are high and steep, so that the tributary streams are not very long, but they have large falls. On the north the river is flanked by the Blue Ridge, whose highest peaks attain elevations of more than 4,000 feet. On the south, and lying closer to the stream, are the Brushy Mountains, a low ridge which in places attains an elevation of 2,000 feet.

The upper part of the valley of the Yadkin is very well wooded, and the forests, with the deep soil on the mountain sides, tend to make the flow of the stream more constant than might be expected in the absence of lakes or marshes to act as regulators. The highest flood of which there is any record extant was in 1878, when the river rose 23 feet. The floods are of short duration, generally subsiding in from thirty-six to forty-eight hours. It is said that twenty-five years ago high floods very rarely occurred, and their frequency now is accounted for by the clearing of the hills and the removal of obstructions from the river.[a] The lowlands are more frequently overflowed than formerly, and more damage is done to the crops. The annual rainfall in the upper valley varies from 44 to 50 inches.

Between Patterson and Wilkesboro the lowlands are in places a mile or more in width and are exceedingly fertile. This region is known as Happy Valley, and is considered to be among the finest agricultural sections of the State. The chief products are corn, wheat, tobacco, cotton, cane, and fruits. The corn and wheat raised are especially good. Pasture land in the immediate vicinity is poor, but along the slopes of the Blue Ridge grazing is better and considerable hay is produced. The climate is salubrious. The Wilkesboro division of the Southern Railway passes up the north banks of the Yadkin as far as the town of North Wilkesboro. The only two towns of any importance along this part of the stream are Elkin and Wilkesboro. Both are growing rapidly and give promise of continual development.

The well-defined river basin of the Yadkin is marked by an apparently unbroken valley floor lying at an average elevation of 1,200 feet. This floor, which rises by a gentle inclination from about 1,100 feet along the river to 1,400 feet at the bases of the bounding ranges, can be seen to best advantage when standing on the steeper slopes of the mountains, as, for instance, on the road from Lambsburg to Cold Spring, in the northern part of Surry County. As soon as one approaches the tributaries or the river itself, it is evident that the valley floor is not continuous, but that it has been deeply trenched by

[a] Ann. Rept. Chief of Engineers U. S. A., 1878, p. 628.

nearly all of the streams belonging to this portion of the Yadkin river system. The trench now occupied by the main river is from 300 feet to 400 feet below the general level of the valley, and varies in width from a half mile to a mile and a quarter. The width of the trench is clearly influenced by varying resistance in the rock series crossed by the stream; the depth, however, seems to increase uniformly downstream, without relation to rock resistance. The bottom of the main trench is covered with alluvial sands, gravels, loams, or clay to a depth of from 15 to 20 feet. Through the bottoms thus formed the river pursues a meandering course, being sunk about 10 feet below the general level of the valley floor at Siloam and not more than 5 feet below in the vicinity of Patterson's mill.

The trenches cut by the tributary streams are narrower than the main trench, have steeper bounding slopes, which are sometimes precipitous, and have narrower bottoms, which often extend far up the streams. Near their mouths the tributary valleys are very narrow, their channels steep, and usually a number of low cascades over resistant layers characterize the debouchments of the streams upon the broader bottoms of the river.

Along the steep slopes of the trench of the main stream, and overlooking the lower bottoms, are two sets of river terraces, which have been partially cut out of the deeply decayed gneissic rocks and partially built up of stratified gravels, sands, and clays. These two terraces are at elevations of 20 and 60 feet above the lower bottoms. In places traces of a third terrace, at about 100 feet, can be seen. Deposits similar in character and form can be found in the tributary gorges, usually at the 100-foot elevation.

SOILS.

In general the rocks of the region are schists of moderate compactness, with gneissic and slaty bands in the vicinity of Blowing Rock. Near Mount Airy the metamorphic crystallines seem to have been cut by compact granitic rocks, which withstand weathering much better than the surrounding formation, and thus have formed low hills standing above the general level (1,200 feet) of the valley floor. The granitic rocks on disintegrating produce clays and sands; but the areas covered by the resulting soils are small. The metamorphic rocks generally produce clayey subsoils, with a not very porous top soil. In some localities an unusual amount of quartz in the rocks has resulted in the production of sandy soils. Thus the soils of the valley floor are generally rather heavy, with an impervious subsoil. Consequently neither heavy rains nor the average moderate precipitation penetrates to a great depth. Instead the water gathers into surface rills and rapidly finds its way into the streams, at the same time carrying with it a large portion of the looser surface soil.

The nearly level elevated valley floor has been almost wholly cleared of timber. In it areas of remarkable fertility occur at inter-

vals. These have been extended in size and in depth by the wash from the mountain sides. The soil of the slopes on the north side of the stream is largely siliceous and is well mixed with humus and vegetable mold, affording rich pasture and farm lands. The soil of the mountain slopes on the south side of the river is shallow and comparatively poor.

FORESTS.

The forest growth consists chiefly of oak, chestnut, poplar, and linn, with some pine, and with occasional patches of hemlock. Near the railroad considerable cutting of the best trees has been done, but in many parts of the area the timber is practically untouched. Considerable damage has also been caused by forest fires, though in most places the injury from this cause has not been serious or permanent.

DISCHARGE MEASUREMENTS.

During the investigation the following measurements were made of the river at various localities along its course:

Discharge measurements of Yadkin River.

Date.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.			*Feet.*	*Sec.-feet.*
June 20	Second ford below Patterson's mill	N. C. Curtis and Cleveland Abbe, jr.	13.30	182.0
July 14	do	do	13.50	100.3
Aug. 7	do	do	13.40	76.2
Sept. 26	do	do	13.53	43.0
June 21	Wilkesboro	do	26.73	780.0
June 23	do	do	26.14	1,737.0
July 4	do	do	26.83	663.0
July 12	do	do	27.05	488.2
Aug. 6	do	do	27.20	386.0
Oct. 1	do	do	27.20	369.1
Nov. 4	do	do	26.22	1,331.0
1901.				
June 8	do	do	25.81	1,762.0
June 14	do	do	16.50	11,667.0
June 15	do	do	14.22	12,582.0
June 18	do	do	23.80	3,727.0
1900.				
July 11	Siloam	do	2.90	1,367.0
Aug. 3	do	do	2.60	1,218.0
Oct. 31	do	do	3.10	1,469.0

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in the above table at Siloam. In making all of the other measurements, however, in each case a bench mark was established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In these cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

For several years the Survey has maintained a gaging station on Yadkin River at Salisbury, also one at Norwood, both farther downstream than the present investigation extended, the results of which have been published in the annual reports. The station at Norwood was discontinued in January, 1900.

WATER POWERS.

Between Patterson's mill and the town of Patterson, about 4 miles farther upstream, Yadkin River is a meandering stream, with slight fall, occupying a wide, terraced trench about 80 feet below the general level of the trenched valley floor already described. Although there are many shoals with gravelly bottoms between Patterson and the mouth of Little Ararat River, there are no good water powers, because of the broad, alluvium-lined valley, which offers no anchorage for dams; nor are there any sharp falls or even important rapids sufficiently high to furnish useful power. About 1 mile above Brown's ford, 4 miles west of Wilkesboro, what seem to be gravelly shoals in the river accompany a fall in the channel of 5 feet within a quarter of a mile. The bottom lands on the north bank of the river at this place are only 200 feet wide. On the south side, however, they are somewhat wider and seem to afford poorer holding ground. Again, about 3 miles above Ronda the river runs at the bottom of a narrow, rock-ribbed trench, and its channel is cut across by rough ledges of hornblende-schist. This locality, with a channel fall of 5 or 6 feet, seems to be the best on the whole stretch of the main stream, having a good foundation for a dam and natural abutments.

There are no mills on the main stream between Patterson's mill and Siloam. At Patterson, 4 miles upstream from the mill mentioned, there are two mills. The first one, a cotton mill, has a fall of about 10 feet. The other one, a few hundred yards upstream, is a woolen factory operated during the greater part of the year by water power, but having an auxiliary steam plant for use during unusually low water. This mill uses a fall of 25 feet, obtained by sluicing the water 200 yards from a 15-foot dam.

Above Patterson the river occupies a narrow, rock-walled gorge, affording many good powers, though a number are at present inaccessible. About 1 mile above the woolen mill and sawmill just mentioned the whole volume of the river crosses Ripshin Mountain through a narrow water gap floored and flanked to a great height by firm gneiss and schist. The channel at this point has a drop of certainly 5 feet within half as many rods, and a dam 100 feet long and 10 feet wide would completely flood broad meadow lands to a distance of a mile upstream. About 1⅛ miles upstream from this gap through Ripshin Mountain a small mill has been built to utilize a fall of 10 feet, and on Mill Fork, one-fourth mile above its confluence with the Yadkin, another mill, with an 8-foot fall, has been established, while about 1 mile above Kirby Gap this same stream (Mill Fork) has an almost perpendicular fall which is estimated to be 250 feet.

The following table contains interesting data regarding the elevation, fall, etc., of the river in various portions of its course above the mouth of Ararat River:

Elevation, fall, etc., of Yadkin River above Ararat River.

Place.	Distance from Siloam.	Elevation.	Distance between points.	Fall between points.	Fall per mile.	Average annual fluctuation.
	Miles.	*Feet.*	*Miles.*	*Feet.*	*Feet.*	*Feet.*
Mouth of Ararat River		798				6
			50	130	2.6	
Wilkesboro	50	928				7
			32	322	10.06	
Patterson	82	1,250				5
			13	2,250	173.07	
Head of stream	95	3,500				

Above its junction with Mill Creek the river pursues a winding course, flowing at the bottom of a very deep and narrow gorge, with an average fall of about 50 feet to the mile.

Below Ararat River the valley of the Yadkin averages 50 miles in width, much of it composed of fertile bottom lands. At several places, however, the hills close in upon the river, confining it between steep and rocky banks. In this lower portion of its course there are many places where water power could economically be developed. The following table gives the locations of the principal powers:

Summary of water powers on Yadkin River.[a]

Locality.	Distance from State line.	Drainage area.	Total fall.		Gross horsepower available.			Remarks.
			Height.	Length of shoal.	Minimum.	Minimum average for the low season.	Average for the low season of average dry years.	
	Miles.	*Sq. mi.*	*Feet.*	*Feet.*				
Bluitts Falls	12.0	6,650	9.00	1,000	1,500	1,900	2,170	
Grassy Island Shoal	13.0	6,624	36.00	[b] 4.5	5,970	7,600	8,680	
Swift Island Shoal	42.0	4,323	18.00	[b] 2.5	1,942	2,476	2,796	
Gunsmith Shoal	57.5	4,300	9.50	2,500	1,020	1,300	1,470	
Narrows	60.0	3,938	91.00	[b] 5	8,954	11,375	12,922	
Bull Island Shoal	65.0	3,800	29.00	[b] 2	2,854	3,625	4,118	Undeveloped.
Penningtons Shoal	67.0	3,900	74.00	[b] 4.5				
Milledgeville Shoal	70.0	3,500	14.00	[b] 0.7	1,378	1,750	1,988	
Motts Falls	72.3	3,400	13.50	[b] 0.8				Do.
Bald Mountain Shoal	73.8	3,300	8.50	[b] 0.5				Do.
Flat Swamp Mountain Shoal.	78.3	3,000	10.20	[b] 0.5				Do.
Fries Manufacturing and Power Co.	131.5	1,865	10.00	1,600				Rock bottom.
Langenhour & Neason's dam.	138.5	1,827	4.57		220	280	325	Do.
Shallow Ford Shoal	145.0	1,812	7.89	5,560	375	485	550	Rock and gravel bottom.
Shoal above Shores Island.	155.2	1,638	7.73	9,662	330	430	490	Do.
Bean Shoal (head)	164.7	1,521	39.17	[b] 4	1,560	2,030	2,320	Rock bottom.
Lime Rock Shoal	169.3	1,165	10.62	[b] 2.59	325	425	490	Do.
Shoal below Rockford.	174.8	1,097	8.38	4,500	240	320	360	Do.
Seven Island Shoal	177.0	1,066	4.02	2,630	112	145	165	Do.
Long Shoal	182.0	949	11.18	[b] 1.61	205	335	385	Do.
Woodruff Fishtrap Shoal.	185.0	925	4.55	1,800	105	134	155	Do.
Mitchell Island Shoal	186.6	925	4.00	2,740	90	115	135	Gravel bottom.
Swan Creek Shoal	196.7	739	5.40	3,160	100	125	145	Rock bottom.
Reeve Island Shoal	206.5	540	3.86	2,700	50	65	75	Rock and gravel bottom.
Blair Island Shoal	216.5	420	3.44	1,700	36	46	53	Gravel bottom.

[a] From Bull. No. 8, N. C. Geol. Survey.

[b] Miles.

It will be seen that the fall is not in the form of direct vertical drops, but in shoals of considerable length. One of the greatest drawbacks to the development of power in a large part of the Yadkin is the lack of proper means of transportation.

TRIBUTARIES OF YADKIN RIVER.

DISCHARGE MEASUREMENTS.

The following measurements were made of the important tributaries of the Yadkin to and including Ararat River, in order downstream:

Discharge measurements of upper tributaries of Yadkin River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1900.				*Feet.*	*Sec.-ft.*
June 20	Elk Creek	One-fourth mile above ford	Cleveland Abbe, jr., and N. C. Curtis.	2.4	119.0
July 13	do	do	do	2.43	61.0
Aug. 6	do	do	do	2.60	37.0
Sept. 26	do	do	do	2.61	30.0
June 21	Stony Creek	Footbridge at Colberts	do	2.65	78.4
July 13	do	do	do	2.70	80.5
Aug. 6	do	do	do		50.0
Sept. 26	do	do	do	2.87	31.10
June 21	Louis Fork of Yadkin River.	Footbridge on Mount Pleasant road.	do	3.10	127.0
July 13	do	do	do	3.23	99.0
Aug. 6	do	do	do	3.30	69.0
Sept. 26	do	do	do	3.33	63.0
June 23	Reddie River	North Wilkesboro	do	24.73	218.1
July 12	do	do	do	25.15	98.1
Aug. 4	do	do	do		93.0
Oct. 1	do	do	do	25.25	60.2
June 23	Mulberry River	Trestle of Greensboro and Wilkesboro division of Southern R. R.	do	21.93	108.4
July 3	do	do	do	22.25	50.3
Aug. 4	do	do	do	22.50	39.25
Sept. 27	do	do	do	22.42	61.2
Nov. 2	do	do	do		55.0
June 25	Roaring River	Greensboro and Wilkesboro R. R. bridge.	do	23.68	520.2
July 9	do	do	do	25.45	161.4
Aug. 4	do	do	do	25.75	117.0
Sept. 27	do	do	do	25.13	109.0
Nov. 2	do	do	do	24.27	197.0
Sept. 27	Big Bugaboo Creek	Ford of road from Roaring River to Elkin.	do	1.28	30.0
June 25	Big Elkin River	Greensboro and Wilkesboro R. R. bridge.	do	24.53	65.0
July 9	do	do	do	25.95	29.0
Aug. 4	do	do	do		24.0
Sept. 27	do	do	do	26.22	27.0
June 26	Mitchell River	do	do	21.63	383.1
July 10	do	do	do	24.00	139.2
Aug. 3	do	do	do	24.25	119.0
Sept. 28	do	do	do	24.25	10[illegible].0
Nov. 1	do	do	do	23.89	216.0
June 26	Fisher River	Greensboro and Wilkesboro R. R. trestle.	do	20.93	549.0
July 10	do	do	do	23.38	172.0
Aug. 3	do	do	do	23.60	126.0
Sept. 28	do	do	do	23.72	119.0
Nov. 1	do	do	do	23.70	235.0
June 27	Ararat River	do	do	23.9	801.0
July 11	do	do	do	26.0	317.1
Aug. 2	do	do	do	26.25	265.4
Sept. 29	do	do	do	26.46	242.5
Oct. 31	do	do	do	25.68	307.0

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

The drainage basins and water powers of the principal tributary streams are briefly described on the following pages. Practically all of the tributaries whose water powers are worth considering flow into the Yadkin from the north. The divides and spurs, between which are the basins of the tributary streams, are seldom more than a mile wide and form many picturesque coves and valleys.

ELK CREEK.

This stream was measured at a foot log about one-fourth of a mile above the road ford at Elkville. At the point of measurement and for a short distance above and below are cascades over broad ledges of gneiss, and the stream is bounded by steep, rocky slopes. The natural fall is estimated to be at least 10 feet within 200 yards. Higher up the stream there are undoubtedly other fair powers, but they were not examined.

STONY CREEK.

This stream enters the Yadkin from the north about 6 miles below Elkville, and possesses a splendid power at its mouth and for a short distance upstream. Throughout the last half mile of its course the banks are the steep, rocky sides of a narrow, V-shaped gorge. Within this distance the stream has an estimated fall of at least 50 feet, flowing over a series of ledges in falls or cascades of from 6 to 10 feet each. Just at the mouth of the creek there stands a combined sawmill and gristmill driven by turbine power. The dam is only 6 feet high, but is so favorably placed on ledges that about 18 feet head is obtained. This is an excellent mill site, but the road leading down to it from the surrounding country is poor and is on a steep grade. The stream was measured at a foot log about 3 miles above its mouth, where it flows through a sandy meadow or bottom one-fourth of a mile wide. So far as examined this stream offers a number of good mill sites, for its valley is everywhere bounded by steep mountain sides, and in many places is narrow, by reason of the occurrence of bands of resistant gneiss and schist.

LOUIS FORK.

This stream has a large drainage basin, served by its two branches, East Fork and West (or South) Fork. The valleys of these branches are generally open and are largely cleared, the bottom lands, of which there is a large area, being under cultivation. The discharge was measured (see table on page 164) at a foot log where the Mount Pleasant road crosses the stream, just below the confluence of the East and West forks. The bottom at this place is rather sandy and gravelly, with some large bowlders. About one-fourth of a mile downstream, however, the creek leaves the meadows and enters a narrow,

steep-sided gorge containing many rocky ledges. There are one or two small gristmills on the forks above the point of measurement, which is nearly 3 miles from the mouth, but so far as known there are none below it.

UNNAMED TRIBUTARY EAST OF LOUIS FORK.

There is a small stream which heads in the mountains northeast of Purlear and enters the Yadkin from the north about a mile west of Brown's ford, on which there is considerable fall, over rock ledges, at the mouth. This fall is utilized by a gristmill and yields a head of 10 feet, although the dam is only 5 feet high. The stream is so small that it was not possible to measure its discharge satisfactorily with the large meter. Judging from the wooded character of its valley, however, it has a fairly uniform flow throughout the year, and its steep grade gives much more power than is now used.

REDDIE RIVER.

This river heads far up among spurs of the Blue Ridge, between Horse Gap on the west and Mulberry Gap on the east. Its headwaters are moderately well wooded, but along its middle course there is more open and cleared valley land. There are several mills on the stream, the more important ones being a gristmill at Whittington and two mills at its mouth, just above North Wilkesboro. The latter mill site is an admirable one, the shoal being 10 or 15 rods wide, rock-floored, and excellent rock abutments being furnished by the ledges on either bank. The natural fall in the channel is about 10 feet, half of which is utilized, by means of a 9-foot dam, by a gristmill and flour mill on the west bank. One hundred yards below the dam a sash factory uses a fall of about 14 feet, obtained by sluicing the water from the dam to the east bank of the stream.

The river is reported to be not subject to rapid fluctuation, thus distinguishing it from most of the other streams of the neighborhood.

MULBERRY RIVER.

This river also rises far back in the Blue Ridge, starting near Mulberry Gap and flowing southeastward. Its valley, which is rather broad, is covered with alluvium and offers relatively few mill sites. The average grade of the channel seems to be much less than that of most of the streams of the district. In the upper stretches falls and rapids are more numerous than in the lower portions of its course. About halfway between Mulberry and Halls Mills there is a shoal which affords fall for Wood's gristmill and sawmill, giving the wheel 8 feet head. So far as known this is the only mill on the stream. At the crossing of the road between North Wilkesboro and the town of Roaring River there is an excellent little fall of about 6 feet, due to

a broad ledge of rock which crosses the stream and furnishes a good abutment on the west bank. At the Southern Railway trestle there is also a series of cascades furnishing 6 feet fall, with good abutments on the east bank. The river was measured at the trestle, which is about halfway between the Yadkin and the steep hillside forming the northern boundary of that river's flood plain.

ROARING RIVER.

This stream is much larger than Mulberry River and possesses many good water powers. Those at present best known are the one about 4 miles below Dockery, which is near the junction of the eastern and western forks, and the one at the mouth of the stream.

Just above the confluence of the two chief forks a small stream enters the western fork from the southwest. Where the road from Round Mountain to Dockery crosses it the average fall is 100 feet per mile. Here Spencer Blackburn has built a small mill which uses a fall of 20 feet. Passing on to the two forks and to the main stream below the ford of the eastern road from Round Mountain to Dockery, the river is very rapid and is confined between high and steep banks. Its fall averages 20 feet to the mile, and the shoals, including the Big Shoals, cover a distance of about 1 mile. All of this fall can be made to furnish excellent power, both on the main stream and on the northern fork, which joins the river at this point, after draining a region to the northeast lying between Hank Store and Lomax.

Though narrow and steep sided in the vicinity of the Big Shoals, the valley widens a short distance below, and the stream possesses no valuable powers until about one-fourth mile above the railway trestle at its mouth, where a series of cascades over firm rock ledges causes the channel to drop 15 feet within half as many rods. At the trestle the valley opens out into the sandy flood plain of the Yadkin.

BIG ELKIN RIVER.

This stream has three noteworthy falls, which give it an important place among the water powers of the upper Yadkin Valley. The most important falls, or series of falls, so far as water power is concerned, are Carters Falls, about 3 miles above the mouth of the stream, at a place known as Cool Spring Church. When visited during the summer of 1900 these falls had a comparatively small volume of water. They are occasioned by a broad band of resistant hornblende-gneiss. The upper fall, which is the greater, was measured by a hand level and found to be 60 feet in a distance of 100 yards. From the foot of this fall the stream runs over low ledges for an eighth of a mile to a lower fall which is about 15 feet high. The latter fall is utilized by a small turbine-driven gristmill on one bank and by a small lumber mill on the other bank. The owner of

the land states that he has measured the total fall here, from the head of the upper to the foot of the lower falls, by means of accurate instruments, and finds it to be 92 feet, which seems quite possible. The banks of the gorge are steep and of firm rock, affording the finest water-power site between Ararat River and the source of the Yadkin.

About a half mile below the lower falls mentioned there is a fall of about 25 feet, part of which has been utilized by Butler's gristmill, which has a dam 6 feet high yielding 14 feet head. By extending the race a few yards farther downstream a head of 20 feet could be obtained. During high water there is a maximum rise of 3 feet above the top of the dam.

The other powers are near the mouth of the river, in the towns of Elkin and Elkin Valley. At the former place, where there is a favorable rock bottom and decided falls, are two dams; at the latter place, which is higher upstream, there is a gristmill and flour mill with a 10-foot dam and a fall of 18 feet.

MITCHELL RIVER.

This stream was measured just below a series of low rapids over rocky ledges, marking the point of transition from the rocky channel of back country to the sandy flood plain of the Yadkin. The fall, about 10 feet, has not been utilized though it is favorably situated. About 1 mile upstream Burch's flour mill obtains power from a tributary—Snow Creek. At Guyer Ford, 6 miles above the mouth, there is a broad shoal which would give 5 to 7 feet fall within a quarter of a mile.

The valley of Mitchell River is similar to that of Fisher River, being rather narrow, with steep side slopes, but it has been somewhat more cleared than the latter valley. Perhaps half the area of the immediate slopes is now bare of trees, while in the valley of Fisher River two-thirds of the timber seems to be standing.

FISHER RIVER.

This stream was ascended only a short distance. No improved mill sites were found, though a number of small mills are reported along its upper course. Many mills, however, are located on small tributaries of the river. The stream is a large one, being 30 to 40 miles long, rising far back upon the Blue Ridge, in about the same latitude as Mount Airy. Probably the only good mill site is at the neck of what is known locally as The Oxbow or The Horseshoe, a semicircular bend in the river about 5 miles southeast of Dobson. The two arms of this loop come within 100 yards of each other at the narrow neck, and there is said to be a difference of 20 feet in the surface level of the river on the two sides. It has been suggested that this difference in level be utilized by piercing the neck with a tun-

neled race, but nothing in that direction has yet been done. At the ford of the road between Snow's mill and Butcher there are shoals due to a fall of perhaps 5 feet in one-fourth of a mile, and at the ford southwest of Butcher there is a long shoal giving 4 or 5 feet fall in 200 yards. The valley appears too wide for dam construction, but just below the second shoal mentioned it narrows and closes in for a short distance.

ARARAT RIVER.

Ararat River is the largest of the upper tributaries of the Yadkin. It rises on the Blue Ridge, about 10 miles north of Mount Airy, at an elevation of 2,500 feet, and flows almost due south for 30 miles, emptying into the Yadkin 1 mile below Siloam. The average fall per mile from the mouth to Mount Airy, a distance of 20 miles, is 14.6 feet. Above Mount Airy, where the fall is much greater, there are a number of small gristmills.

NEW RIVER.

New River rises in Watauga County, N. C., and flows in a general northeasterly direction through Watauga and Ashe counties. It then follows the North Carolina–Virginia State line for about 12 miles, when it turns to the north and joins Kanawha River, its waters finally reaching the Ohio. Just before it intersects the North Carolina-Virginia boundary line there is a confluence of two branches of almost equal size, known as the South Fork and the North Fork. The North Fork drains the eastern slopes of the Iron Mountains along the southwestern border of Ashe County, N. C. Both forks are formed by the junction of several branches which drain the mountain slopes. The total drainage area of the two forks is 631 square miles.

Examination of the drainage basin of the river was made as far down as Oldtown, in Grayson County, Va., about 7 miles below the confluence of the North and South forks. The upper part of the basin is rough and mountainous, the stream flowing through gorges and narrow valleys with rocky slopes and bottoms. The occasional widening of the valleys, however, furnishes favorable sites for dams and mills. The soil is for the most part deep and fertile, making a fine agricultural region. According to the census of 1880, 92,000 acres were under cultivation, 57,000 acres were in grass, and 240,000 acres, or 61 per cent of the whole, were in original timber. The annual rainfall in the basin, as indicated by a single station, viz, Blowing Rock, is about 49 inches, distributed as follows: Spring, 11.3 inches; summer, 16.2 inches; autumn, 9.7 inches; and winter, 11.8 inches. The region is rich in mineral resources, especially in iron and copper, though very little has been done in the way of development.

The total length of the river between the junction of the forks and Oldtown, Va., is about 35 miles, and the average fall per mile about

8.5 feet. The river winds its way in narrow gorges formed by the shutting in of the hills on either bank. Bottom land is therefore scarce. The section of Virginia through which this portion of the river flows is chiefly devoted to stock raising. The land is fertile and the soil deep and of a reddish color. The region is well settled, the people thrifty, and large and well-cultivated farms can be seen everywhere. Wheat and other grains are the chief crops.

During the investigation a gaging station was established (July 31, 1900) near Oldtown, Va., and two measurements were made there (see table below). Measurements were also made of tributaries of the river between the confluence of the North and South forks and Oldtown, as shown in the following table. The basins of the North and South forks are described under separate headings, and the measurements made on those streams and their tributaries are given in the tables on pages 172 and 174.

Discharge measurements of New River near Oldtown, Va., and of its tributaries between confluence of North and South forks and Oldtown.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge
				Feet.	*Sec.-ft.*
1900. July 28	Wilson Creek	2 miles above mouth	Cleveland Abbe, jr., and N. C. Curtis.	6.3	35.1
Oct. 28	do	do	do	6.1	78.0
July 29	Fox Creek	One-fourth mile above mouth	do		85.0
Oct. 28	do	do	do		144.0
1901. June 28	do	do	do		352.0
1900. July 31	Peach Bottom Creek	200 yards above mouth	do	4.9	21.4
Oct. 29	do	do	do		36.0
July 31	Little River	Ford of Independence-Oldtown road.	do	9.1	199.0
Oct. 29	do	do	do		318.2
July 30	Elk Creek	200 yards above mouth	do	4.0	57.1
July 31	New River	Near Oldtown	do	6.6	1,541.0
Oct. 29	do	do	do	6.3	2,293.0

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in the gage height represents an increase in the discharge of the stream.

The water powers of all of the streams mentioned in the foregoing table are excellent, and many of them have already been developed. At the mouth of Wilson Creek there are two mills—the lower one a grain mill with a fall of 12 feet, and the upper one a woolen factory, owned by Fields & Hash. On Peach Bottom Creek, 2 miles east of Independence, is the gristmill of D. C. Mallory. The total fall here is about 65 feet.

SOUTH FORK OF NEW RIVER.

GENERAL FEATURES.

This stream is formed by the confluence of the East Fork, the Middle Fork, and Flannery Fork, near Deckhill, Watauga County, N. C. The Middle Fork, which is the largest of the three tributaries mentioned, rises just north of Blowing Rock, at the boundary line between Watauga and Caldwell counties, at an elevation of between 3,700 and 3,800 feet. The elevation at the junction of the North and South forks being 2,500 feet, the difference in elevation between the head and the mouth of the South Fork is 1,300 feet, the distance 45 miles. This gives an average fall of 29 feet to the mile. As the course of the stream, however, is extremely crooked the slope is hardly 20 feet to the mile. Shoals and available water powers are not numerous on the main stream, but on the branch streams they are more frequent and have been more extensively utilized.

The area drained by the South Fork presents a very great diversity of scenic features. The general course of the stream is parallel to the Blue Ridge. On the north are very high knobs and ridges. The highest of these is Snake Mountain, 5,594 feet high. The scenery presented though not rugged is extremely beautiful. The basin of the river is for the most part closed, and there are no extensive bottom lands.

The proportion of unimproved cleared land in Watauga and Ashe counties is small compared with the agricultural lands. On many of the mountains the timber is practically untouched. The trees, however, are not of the most valuable varieties. They are chiefly maples and chestnuts. The larger portions of the cleared land are devoted to the production of grass and hay, and consequently the raising of cattle and sheep is a most important industry. The chief crops are corn, wheat, buckwheat, and cabbages, to all of which the soil is especially well adapted. Large quantities of apples are also produced. The people are well to do and prosperous. The region is very healthful; typhoid and malarial fevers are unknown.

No railroad has yet penetrated Watauga County, though a route has recently been surveyed and a tax voted. The route surveyed crosses the Blue Ridge at Cook Gap. The country roads are for the most part good and are being improved and kept open for travel. The turnpike between Boone and Blowing Rock is remarkably well graded, and it is possible for loaded wagons to cross the Blue Ridge to Lenoir throughout the year. Lenoir is at present the shipping point for the produce of the county. The people of Ashe County are not so progressive in the matter of road building as are the people of Watauga County.

Both the North Fork and the South Fork are at times swollen by heavy freshets, which are often very destructive to crops on the bottom lands. Occasionally the soil is entirely removed from the bottoms and the bed rock exposed. More often, however, where the current is not very swift, a rich coating of black mud from one-half inch to 4 inches thick is deposited, enriching the lowlands considerably.

DISCHARGE MEASUREMENTS IN BASIN.

During the investigation a gaging station was established on the South Fork at New River, N. C. The measurements made there, as well as those made at Riverside, also the measurements made on the tributaries, are given in the following table, in order downstream:

Discharge measurements of South Fork of New River and its tributaries.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-ft.*
1900. July 28	South Fork of New River	New River	Cleveland Abbe, jr., and N. C. Curtis.	2.70	751.0
Oct. 28	do	do	do	2.60	1,635.0
1901. June 27	do	do	do	3.90	1,976.0
1900. July 18	do	Riverside	do	11.85	165.0
Oct. 25	do	do	do	11.00	741.1
1901. June 24	do	do	do		968.0
Do	do	Ford near mouth of Middle Fork of New River, near Boone.	do	7.10	159.0
Do	West Fork	Near Boone	do	5.40	108.0
1900. July 23	Flannery Fork	Ford of Boone-Blowing Rock road.	do	6.35	10.4
Oct. 24	do	do	do	5.35	107.0
July 23	Middle Fork	Ford of Boone-Aho road	do	5.70	24.4
Oct. 24	do	do	do		234.0
July 23	East Fork	do	do	5.70	10.4
Oct. 24	do	do	do	5.10	109.0
July 18	Meat Camp Creek	One-fourth mile below Moretz.	do	9.00	35.3
Oct. 25	do	do	do	8.65	89.0
1901. June 24	do	do	do	7.90	164.0
1900. July 24	Elk Creek	Elk Crossroads	do	8.00	10.0
July 18	Old Field Creek		do	6.1	19.4
July 24	Gap Creek	One-eigi th mile above mouth.	do	4.85	23.4
July 19	Beaver Creek	At mouth	do	6.00	22.4
July 27	Mulberry Creek	Near mouth	do	5.1	109.0
Do.	Prather Creek	One and one-half miles below Scottville.	do	8.6	25.0

NOTE.—In making the measurements recorded in the above table bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in gage height represents an increase in the discharge of the stream.

WATER POWERS IN BASIN.

There are a number of undeveloped water powers on the South Fork and its tributaries, the chief of which are the following:

On the Middle Fork, about 5 miles from Blowing Rock, there is a fall of possibly 15 feet in 100 feet, with a good dam site, though the space for building purposes is somewhat cramped. On Meat Camp Creek, at Moretz, there is a mill with a dam about 8 feet high. On Elk Creek, at Elk Crossroads, there is a small sawmill. The discharge of this stream is slight, but a fall of about 20 feet has been obtained. On Beaver Creek, at the town of Beavercreek, is Hamilton's corn and flour mill, with a working head of about 10 feet.

Near the mouth of the South Fork are the remains of an old dam. The site is a good one, a rock ledge running entirely across the stream and high hills shutting in close on both banks. A dam 40 feet in height could easily be constructed here. Near Scottville the river makes an almost closed loop, and it has been proposed to tunnel through the neck of the loop and in that way develop a fall. It is said that the difference in the elevation of the surface of the water on the upper and lower sides of the loop is about 30 feet.

Owing to the steep slopes of the adjacent mountains the river and its tributaries are subject to floods, and dams and buildings for the development of the water powers would have to be built strong and substantial.

NORTH FORK OF NEW RIVER.

GENERAL FEATURES.

The North Fork is formed by the junction of Hoskin Fork and Brush Fork in the extreme southwestern part of Ashe County.

The character of the region through which it flows is more mountainous than the basin of the South Fork; the same general agricultural and forest conditions prevail here as in the latter basin. The stream is not so tortuous as the South Fork, but its side streams are more numerous and the fall greater. Its total length is about 30 miles. The difference in elevation between its head and the junction with the South Fork at Weaversford is 1,800 feet, making the average fall per mile 60 feet.

Its main upper branch, Hoskin Fork, rises on the eastern slope of Snake Mountain, at an elevation of 4,300 feet. It flows between closed hills, and its flood plain is very narrow.

The ratio of cleared to forest-covered land in the watershed is estimated to be about 1 to 5. The region about the headwaters is very thinly settled. The scenery is magnificent, especially near Creston and Solitude. The cleared land is chiefly devoted to cattle grazing.

DISCHARGE MEASUREMENTS IN BASIN.

On July 27, 1900, a gaging station was established on the North Fork at Weaversford, N. C. The measurements made there, as well as those made at other points along the river, also the measurements made on its tributaries, are given in the following table, in order downstream:

Discharge measurements of North Fork of New River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-ft.*
1900. July 28	North Fork of New River.	Weaversford	Cleveland Abbe, jr., and N. C. Curtis.	0.60	538.0
Oct. 27	do	do	do	0.90	708.0
1901. June 27	do	do	do	1.40	1,377.0
June 20	do	Below mouth of Laurel Creek	do	1.00	313.0
1900. July 21	do	1 mile below Creston	do	6.7	49.3
Oct. 26	do	do	do	6.0	194.0
1901. June 20	do	do	do	5.5	196.0
1900. July 20	do	¼ mile from Creston, on road to Solitude.	do	2.65	32.2
Do	Threetop Creek	Creston	do	6.75	120.0
July 21	do	do	do	7.25	37.0
July 20	Big Laurel Creek	100 yards above mouth	do	6.40	26.2
Oct 26	do	do	do	6.30	80.4
July 20	Buffalo Creek	¼ mile above mouth	do	5.43	44.0
Oct. 26	do	do	do		67.0
1901. June 20	do	Near Jefferson	do	4.30	140.0
1900. July 25	Horse Creek	¼ mile above mouth	do	6.6	34.3
Oct. 27	do	do	do	6.05	140.0
1901. June 25	do	do	do	5.35	444.0
1900. July 25	Helton Creek	Below Peasley's mill	do	4.28	30.0
Oct. 27	do	do	do		105.0

NOTE.—At regular stations of the Geological Survey gages are installed by which the rise of the river is measured, an increase in the gage height representing an increase in the discharge of the stream. This is true of the measurements in the above table made at Weaversford. In making all of the other measurements, however, in each case a bench mark was established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. In the latter cases, therefore, an increase in the gage height means a lowering of the water surface and a corresponding decrease in the discharge of the stream.

WATER POWERS IN BASIN.

There are a number of water powers in the basin. Those of Threetop Creek are very good. Four mills were observed, with falls ranging from 6 to 15 feet. Shoals and dam sites are numerous. At the falls of Long Hope Creek, a branch of Threetop Creek, there is a total fall of 300 feet in 400 yards. The average discharge of Long Hope Creek is about 10 second-feet. On the North Fork about 3 miles west of the mouth of Buffalo Creek, near Dresden, there is an important water power which at one time was utilized, but the dam was destroyed by a freshet and has not been rebuilt. The hillsides at this point shut

LOWER FALLS OF CULLASAGEE CREEK, NORTH CAROLINA, A TRIBUTARY OF LITTLE TENNESSEE RIVER.

OCONALUFTY VALLEY, NORTH CAROLINA.

in close, and a rock ledge extends across the stream. A fall of 30 or 40 feet could readily be obtained. Horse Creek and Helton Creek are both large streams with considerable fall. No water powers were observed on the former. A combined sawmill and gristmill is located about a half mile above the mouth of Helton Creek. The fall obtained is about 10 feet and the power is developed by turbines. This is also the site of the old Helton iron works, where hammered iron was formerly worked, the ore being obtained in the vicinity. On the North Fork about 2 miles from its mouth is Dixon's corn and flour mill. A dam about 8 feet in height has been constructed here. The flume leading to the forebay is a tunnel cut through a projecting shelf of rock, behind which is a mill house. A masonry dam 40 feet high could be constructed and the power greatly increased.

STREAMS SOUTHWEST OF FRENCH BROAD RIVER.

South and west of the region already described is a large, mountainous area with many of the same characteristics. From this territory flow the headwaters of four of the largest rivers in the Southeastern States. First comes the Tennessee River, the basins of several of the largest branches of which, namely, the Holston, the Watauga, the Nolichucky, and the French Broad, have been described in detail in this paper. Farther south are the Oconalufty, the Tuckasegee, the Nantahala, the Hiwassee, the Okoee, and other rivers which enter the Tennessee and after a long and winding course add their waters to the Mississippi. (Typical views of these streams are shown in Pls. XXXIX to XLIV.) The second large river is the Savannah, which receives numerous tributaries and flows in a southeasterly direction into the Atlantic. The third stream is the Apalachicola River, which with its chief tributary, the Chattahoochee, rises close to the headwaters of the Tennessee and after a southerly course between Georgia and Alabama and through Florida enters the Gulf of Mexico at Apalachicola. The fourth large stream is the Mobile, which receives its headwaters from the mountains of Tennessee and northern Georgia, through the Coosa, the Conasauga, and the Etowah, and flowing through the State of Alabama enters the Gulf at Mobile.

Hydrographic studies and numerous measurements of discharge, in charge of Prof. B. M. Hall, have been made by the United States Geological Survey of the headwaters of all of these streams and of their chief tributaries. Most of the streams rise on the steep slopes of the mountain sides, at elevations of from 2,000 to 4,000 feet above sea level, and have large falls throughout their courses. In many places the streams flow through mountain gorges with steep, vertical sides and with very small flood plains.

Only a small proportion of the region is under cultivation, the greater part being still covered with the original forest growth, consisting of oak, hickory, chestnut, poplar, locust, pine, buckeye, linn, ash, maple, sassafras, walnut, and other varieties. The ground is

frequently covered with trailing arbutus, maidenhair and other ferns, deep-green mosses, and a great variety of wild flowers and rare medicinal plants. The climate is mild throughout the year, making it a fine resort in winter as well as in summer. Wild animals, such as deer, bears, and wolves, once so numerous, are now nearly extinct, but there are still many wild-cats, catamounts, minks, foxes, opossums, ground hogs, polecats, weasels, wild turkeys, pheasants, squirrels, rabbits, quails, etc. The land now under cultivation is practically all that is available for ordinary farming, the remainder being steep, rocky, and rugged, with only occasional patches of deep, fertile soil. Near the rivers considerable timber has been cut, but the lumbering has not extended far up the mountain sides. Means of transportation are exceedingly meager, the Murphy branch of the Atlanta, Knoxville and Northern Railway being about the only outlet. For this reason the few farming products that are raised can not be transported economically to the populated districts, so that there is little incentive to agricultural pursuits. The greater portion of the grain raised is made into moonshine whisky, and the summer apples are largely used for apple-jack. Wheat, cabbages, Irish potatoes, and the hardier fruits grow well.

The mineral resources are practically untouched and comparatively unknown, but they are evidently important and varied. Gold, corundum, asbestos, marble, talc, kaolin, ocher, iron, and mica are known to exist. The whole region is sparsely inhabited. Water powers are very numerous, though few are developed, and most of these on only a small scale, for gristmills and sawmills. The large undeveloped powers on the lower parts of the streams are well distributed and are very valuable for manufacturing purposes. After the rivers leave the mountain region and flow across the broad, elevated plains, large falls frequently occur, some of which have in recent years been developed and have proved to be most lucrative investments.

The results of the measurements upon the streams in this region are given in the following tables, arranged in chronologic order:[a]

Discharge measurements of tributaries of Tennessee River north of Hiwassee River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1901.				*Feet.*	*Sec. ft.*
Feb. 18	Conasauga Creek	Near Cambria, Tenn	B. M. Hall and assistants.		101
Feb. 19	Tellico River	1¼ miles above mouth	do		316
Do	Little Tennessee River.	¼ mile below mouth of Tellico River.	do	3.10	4,774
Feb. 20	Little River	1 mile above mouth	do		374
Feb. 21	West Fork of Little Pigeon River.	At bridge just above mouth	do		133

[a] In making the measurements recorded in these tables bench marks were established and measurements were made, by means of a steel tape, of the distance from the bench mark to the surface of the water. An increase in the gage height, therefore, means a lowering of the water surface and a corresponding decrease in the discharge of the stream, the reverse of the results at the regular stations of the Survey, where gages are installed and where an increase in gage height represents an increase in the discharge of the stream.

TUCKASEGEE RIVER NEAR DILLSBORO, N. C.

TUCKASEGEE FALLS, NORTH CAROLINA.

Discharge measurements of tributaries of Tennessee River north of Hiwassee River—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1901.				*Feet.*	*Sec.-ft.*
Feb. 21	Little Pigeon River	At bridge just above junction with West Fork of Little Pigeon.	B. M. Hall and assistants.	.....	167
Feb. 22	East Fork of Little Pigeon River.	Near mouth	do	.....	[a]30
Do	Cosby Creek	At mouth	do	.....	60
Feb. 23	Big Pigeon River	At bridge above mouth of Cosby Creek.	do	.....	778
Apr. 3	Tellico River	At bridge 1¼ miles above mouth.	do	.....	2,580
Do	Little Tennessee River.	McGhee, Tenn	do	.....	30,536
Apr. 4	Little River	Halfway between Louisville and Knoxville, Tenn., at A., K. and N. Ry. bridge.	do	.....	2,012
Sept. 11	Collins River	McMinnville, Tenn	do	2.60	310
Nov. 4	Little Tennessee River.	McGhee, Tenn	do	2.50	2,675
Do	Tellico River	At bridge 1¼ miles above mouth.	do	.....	180

[a] Estimated.

Discharge measurements of Hiwassee River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1901.				*Feet.*	*Sec.-ft.*
Jan. 10	Stanley Creek	1 mile above mouth	B. M. Hall and assistants.	.....	49.0
Do	Big Creek	Near mouth	do	.....	86.0
Jan. 11	Noontootly Creek	At foot log ¼ mile from mouth.	do	.....	207.0
Do	Toccoa River	At Van Sant's bridge	do	5.05	2,475.0
Do	Skeenah Creek	1 mile above mouth	do	.....	109.0
Jan. 12	Rock Creek	Near mouth	do	.....	132.0
Do	Cooper Creek	Bridge 1 mile above mouth	do	.....	387.0
Do	Toccoa River	1¼ miles above mouth of Cooper Creek.	do	.....	396.0
Do	Mill Creek	At mouth	do	.....	122.0
Do	Toccoa River	Just above mouth of Mill Creek.	do	.....	43.0
Jan. 14	Suches Creek	Near mouth	do	.....	64.0
Do	Toccoa River	Just below Suches Creek	do	.....	175.0
Do	Coosa Creek	Bridge about 2¼ miles from mouth.	do	.....	75.0
Do	Nottely River	Bridge 1¼ miles from Blairsville, Ga.	do	1.45	450.0
Do	Butternut Creek	Just below bridge at mouth	do	.....	32.0
Jan. 15	Arququah Creek	At Choestoe road	do	.....	40.0
Do	Town Creek	¼ mile from mouth	do	.....	85.0
Do	Stink Creek	1 mile above mouth	do	.....	48.0
Do	Nottely River	At foot log just above mouth of Stink Creek.	do	.....	131.0
Do	Wolf Creek	On south side of Nottely River	do	.....	55.0
Jan. 16	Young Cone Creek	1 mile above mouth	do	.....	94.0
Do	Ivy Log Creek	¼ mile above mouth	do	.....	33.9
Jan. 17	Nottely River	At Thompson's bridge at Ivy Log, Ga.	do	1.20	616.0
Jan. 18	Brasstown Creek	At bridge near mouth	do	.....	149.0
Jan. 21	Hiwassee River	Just above mouth of Hightower Creek.	do	.....	152.0
Do	Bell Creek	At mouth	do	.....	24.0
Do	Hightower Creek	Near mouth	do	.....	116.0
Jan. 22	Hiwassee River	Bridge 1¼ miles below Hiwassee, Ga.	do	.....	306.0
Jan. 24	Hemptown Creek	Just above mouth of Youngstone Creek.	do	.....	159.0
Do	Hothouse Creek	About 2 miles above mouth	do	.....	75.0
Jan. 25	Greasy Creek	Near mouth	do	.....	88.0
Jan. 26	Okoee River	Parksville, Tenn	do	.....	1,602.0
Aug. 19	Toccoa River	1¼ miles south of Gaddistown, Ga.	do	.....	67.4
Aug. 20	Williams Creek	¼ mile south of Gaddistown, Ga.	do	.....	22.8
Do	Nickle Creek	¼ mile south of Gaddistown, Ga.	do	.....	12.8

Discharge measurements of Hiwassee River and tributaries—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1901.				*Feet.*	*Sec.-ft.*
Aug. 20	Toccoa River	½ mile southeast of Gaddistown, Ga.	B. M. Hall and assistants.		147.6
Do.	Suches Creek	1 mile northeast of Gaddistown, Ga.	do		144.0
Do.	Cooper Creek	Near fork between Gaddistown and Blairsville, Ga.	do		251.5
Do.	Mulky Creek	do	do		75.0
Do.	Nottely River	1 mile southwest of Blairsville, Ga.	do		955.0
Aug. 21	Christopher Creek	2½ miles southeast of Blairsville, Ga.	do		39.1
Do.	Arququah Creek	3½ miles southeast of Blairsville, Ga.	do		96.0
Do	Foun Creek	6 miles southeast of Blairsville, Ga.	do		279.0
Do	Stink Creek	Near Choestoe, Ga	do		167.0
Do	Choestoe Creek	5½ miles southeast of Choestoe, Ga.	do		160.0
Aug. 23	Miller Creek	¼ mile northeast of Blairsville, Ga.	do		87.0
Do.	Brasstown Creek	1½ miles southwest of Young Harris, Ga.	do		139.0
Aug. 26	Long Bullet Creek	3 miles northwest of Hiwassee, Ga.	do		*26.0
Do.	Hog Creek	1½ miles northwest of Hiwassee, Ga.	do		42.0
Do.	Hiwassee River	1 mile northwest of Hiwassee, Ga.	do		1,039.0
Do.	Fodder Creek	3 miles southeast of Hiwassee, Ga.	do		110.7
Do.	Hiwassee River	3 miles north of Mountain Scene, Ga.	do		529.8
Do.	Cinth Creek	2 miles north of Mountain Scene, Ga.	do		89.0
Aug. 27	Hiwassee River	¼ mile north of Mountain Scene, Ga.	do		92.0
Do.	Owl Creek	1 mile north of Mountain Scene, Ga.	do		87.1
Aug. 21	Fightingtown Creek	8 miles from mouth	do		236.0
Aug. 22	Weaver Creek	2 miles from mouth	do		97.0

*Estimated.

Discharge measurements of Duck and Elk rivers, Tennessee.

Date.	Stream.	Locality.	Hydrographer.	Discharge
1901.				*Sec.-ft.*
Feb. 9	Duck River	Columbia, Tenn	Max Hall	2,418
Do.	Elk River	Fayetteville, Tenn	do	1,858
Apr. 19	Duck River	Columbia, Tenn	do	9,504

Discharge measurements of tributaries of Savannah River.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1901.				*Feet.*	*Sec.-ft.*
Apr. 24	Rocky River	5½ miles northwest of Calhoun Falls, S. C.	B. M. Hall and assistants.		546.0
Aug. 12	do	do	do		448.0
Aug. 13	Little River	5 miles west of Calhoun Falls, S. C.	do	1.35	107.0
Sept. 30	Stekoa Creek	2 miles south of Clayton, Ga.	do		71.0
Do.	Mill Creek	do	do		7.9
Oct. 19	Tiger Creek	Tallulah Falls, Ga., ½ mile above mouth.	do		151.0

WATER-POWER DEVELOPMENT ON TUCKASEGEE RIVER NEAR PAINTER, N. C.

OKOEE RIVER NEAR DUCKTOWN, TENN.

Discharge measurements of Flint River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Mar. 9	Kinchafoonee Creek	Albany, Ga	B. M. Hall	1,208
Do	Muckalee Creek	1¼ miles above mouth	do	1,777
Do	Blue Spring Creek	4 miles below Albany, Ga	do	95
Mar. 26	Kinchafoonee Creek	Albany, Ga	F. A. Murray	1,920
Do	Muckalee Creek	do	do	3,244
Apr. 17	Flint River	1 mile south of Montezuma, Ga	do	5,099
Apr. 18	Kinchafoonee Creek	Albany, Ga	do	1,741
Do	Muckalee Creek	do	do	2,600
July 18	Flint River	1¼ miles east of Montezuma, Ga	do	2,398
July 19	Kinchafoonee Creek	Near Albany, Ga	do	714
Do	Muckalee Creek	do	do	1,001

Discharge measurements of Chattahoochee River and tributaries in Georgia.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Jan. 7	Nancys Creek	7 miles northeast of Atlanta, on Peachtree road.	J. C. Conn	45.9
May 15	Sweetwater Creek	Austell, Ga	K. T. Thomas	188.0
June 25	Chattahoochee River	3½ miles northwest of Gainesville, Ga.	F. A. Murray	1,306.0
Oct. 24	Baldridge Creek	Near Buford, Ga	Max Hall	23.5

Discharge measurements of Chattahoochee River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Jan. 12	Yahoola ditch	1 mile east of Dahlonega, Ga	B. M. Hall and assistants.	39.5
Do	Yahoola Creek	2 miles east of Dahlonega, Ga	do	309.2
Do	Chestatee River	5 miles east of Dahlonega, Ga	do	1,477.1
Jan. 13	East Fork of Tessantee Creek.	3 miles northeast of Cleveland, Ga	do	10.3
Do	Dukes Creek	1¼ miles southwest of Nacoochee, Ga	do	265.2
Do	Chattahoochee River	Nacoochee, Ga	do	424.0
Do	Bean Creek	1 mile east of Nacoochee, Ga	do	12.3
Do	Chickamauga Creek	3½ miles northeast of Nacoochee, Ga	do	109.8
Jan. 14	Soque River	4 miles south of Soque, Ga	do	132.0
Do	Shoal Creek	½ mile above mouth	do	50.1
Do	Soque River	7 miles south of Soque, Ga	do	202.2
Jan. 15	Hazel Creek	Demorest, Ga	do	94.8
Do	Whites Creek	7 miles west of Demorest, Ga	do	38.2
Do	North Prong of Mossy Creek.	Mossy Creek, Ga	do	51.1
Do	South Prong of Mossy Creek.	do	do	25.0
Do	Flat Creek	Glades, Ga	do	22.5
Jan. 16	East Prong of Little River.	2½ miles west of Glades, Ga	do	36.4
Do	West Prong of Little River.	4 miles west of Glades, Ga	do	52.4
Do	Wahoo Creek	4 miles east of Price, Ga	do	89.0
Do	Chestatee River	Newbridge, Ga	do	717.2
Aug. 17	Yahoola Creek	Bridge 1 mile northeast of Dahlonega, Ga.	do	241.0
Do	Tate Creek	1 mile southeast of Porter Springs, Ga	do	32.6
Aug. 19	Cane Creek	3½ miles northwest of Dahlonega, Ga	do	40.5
Aug. 29	Santee Creek	½ mile east of Santee, Ga	do	316.8
Do	Chattahoochee River	1 mile west of Nacoochee, Ga	do	605.6
Do	East Tessantee Creek	2 miles north of Cleveland, Ga	do	27.8
Aug. 30	Chestatee River	3 miles southeast of Dahlonega, Ga	do	744.1
Aug. 31	Crooked Creek	2½ miles southwest of Dahlonega, Ga	do	9.0
Do	Chestatee River	Newbridge, Ga	do	1,141.3
Do	Yellow Creek	2 miles southeast of Newbridge, Ga	do	41.0

Discharge measurements of Etowah River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Jan. 7	Willieo Creek	¼ mile above mouth	B. M. Hall and assistants.	20.1
Jan. 8	Coopers Sandy Creek	1 mile north of Crabapple, Ga	do	9.0
Do	South Prong of Little River.	2 miles south of Freemansville, Ga	do	21.5
Do	North Fork of Little River.	2 miles north of Freemansville, Ga	do	13.4
Do	Smithwick Creek	¼ mile east of Orange, Ga	do	8.2
Do	Buzzard Flopper Creek.	3 miles east of Orange, Ga	do	6.5
Do	Boardtree Creek	1 mile south of Creighton, Ga	do	7.2
Do	Settingdown Creek	Creighton, Ga	do	74.0
Jan. 9	Etowah River	¼ mile north of Hightower, Ga	do	512.4
Do	Yellow Creek	6 miles northeast of Hightower, Ga	do	32.0
Jan. 10	Amicalola River	Afton, Ga	do	166.4
Do	East Amicalola River.	Weir, Ga	do	58.3
Jan. 11	Nimblewill Creek	1 mile south of Randa, Ga	do	383.3
Do	Etowah River	5¼ miles east of Randa, Ga	do	1,881.0
Jan. 17	Cogburris Creek	1¼ miles above mouth	do	14.6
Do	Etowah River	Hightower, Ga	do	676.1
Jan. 18	Settingdown Creek	¼ mile above mouth	do	178.3
Do	Boardtree Creek	1 mile south of Creighton, Ga	do	9.8
Jan. 19	Willieo Creek	¼ mile above mouth	do	31.0
Aug. 31	Etowah River	1 mile west of Auraria, Ga	do	173.0

Discharge measurements of Cahaba River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Jan. 28	Hawkins Spring	¼ mile from Hawkins Station	K. T. Thomas	15.8
Jan. 29	Cahaba River	Sydenton, Ala	do	549.0
Mar. 28	Valley Creek	Adjers Station, Ala	J. R. Hall	378.0
Do	Blocton Creek	Blocton, Ala	do	107.0
Mar. 29	Cahaba River	¼ mile south of Sydenton Station, Ala	do	1,117.0
Do	Buck Creek	¼ mile above mouth	do	179.0
Apr. 25	Cahaba River	2 miles east of Harrell, Ala	do	6,560.0

Discharge measurements of Tombigbee River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Feb. 16	Tombigbee River	Waverly, Miss	K. T. Thomas	6,725
Feb. 18	Luxapelila Creek	Columbus, Miss	do	957
Mar. 7	Yalabusha River	Grenada, Miss	do	1,336
Mar. 11	Luxapelila Creek	Columbus, Miss	do	2,459
Apr. 15	Big Black River	1 mile east of Goodman, Miss	do	614
Apr. 16	Luxapelila Creek	Columbus, Miss	do	873
June 26	do	do	do	109
Oct. 31	do	do	do	126

Discharge measurements of tributaries of Mississippi River.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Feb. 14	Sunflower River	Baird, Miss	K. T. Thomas	3,761
Feb. 15	Sakatouchee River	Mhoon Valley, Miss	do	539

Discharge measurements of Tallapoosa River and tributaries.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Jan. 7	Tallapoosa River	2 miles from Tallapoosa, Ga	Max Hall	329
Feb. 11	Wind Creek	About 4 miles above mouth	J. R. Hall	66
Do	Saugahatchee Creek	Thaddeus, Ala	do	453
Feb. 13	Blue Creek	¼ mile from Susanna, Ala	do	117
Do	Chenehatchee Creek	3 miles above mouth	do	80
Feb. 27	Kowaliga Creek	Kowaliga, Ala	do	154
Mar. 5	Emuckfaw Creek	Near Zana P. O., Ala	do	113
Mar. 11	Moores Creek	1½ miles north of Dudleyville, Ala	do	29
Mar. 12	Chattahaspa Creek	1 mile south of Patillos crossroads, Chambers County, Ala.	do	203
Do	Cohoasoncsa Creek	2½ miles below and west of Milltown, Ala.	do	122
Do	Highpine Creek	½ mile south of Chambers and Randolph County line.	do	89
Do	Beaverdam Creek	1 mile north of Lovina, Ala	do	30
Mar. 13	Cornhouse Creek	Near Level Roads, Ala	do	31
Do	Wildcat Creek	Near Gay P. O., Ala	do	32
Do	Tallapoosa River	About 3 miles below confluence of Big and Little Tallapoosa rivers, at Blakes Ferry.	do	2,400
Do	Crooked Creek		do	183
Do	Hurricane Creek	1 mile north of Almond, Ala	do	29
Oct. 21	Tallapoosa River	Near Tallapoosa, Ga	Max Hall	119
Do	do	do	do	96

Discharge measurements of tributaries of Coosa River in Alabama.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Apr. 5	Choccolocco Creek	1½ miles north of Jenifer, Ala	J. R. Hall	1,170.0
Oct 16	Big Wills Creek	2 miles north of Attalla, Ala	F. A. Murray	107.3
Do	do	do	do	106.8

Discharge measurements of tributaries of Oostanaula River.

Date.	Stream.	Locality.	Hydrographer.	Discharge.
1901.				*Sec.-ft.*
Jan. 7	Mountaintown Creek.	3½ miles from Ellijay, Ga	B. M. Hall and assistants.	162.0
Do	Ellijay River	Ellijay, Ga	do	165.0
Jan. 8	Cartecay River	do	do	250.0
Do	do	Cartecay, Ga	do	207.0
Do	Anderson Creek	1 mile above mouth	do	37.0
Jan. 9	Tickanetley River	1 mile above mouth of Anderson Creek	do	43.5
Jan. 28	Jacks River	Near its junction with Conasauga River.	do	186.0
Do	Conasauga River	1 mile above mouth of Jacks River	do	119.0
Do	Sheets Creek	Just above mouth	do	12.0
Jan. 29	Sumach Creek	At junction of North and South prongs.	do	58.3
Do	North Prong of Sumach Creek.	Near junction of North and South prongs.	do	19.8
Do	South Prong of Sumach Creek.	do	do	38.5
Do	Mill Creek	Near Dunn, Ga	do	41.8
Do	Holly Creek	Near East Mountain, Ga	do	107.0
Do	Rock Creek	Ramsay, Ga	do	41.0
Aug. 19	Talking Rock Creek	Talking Rock, Ga	do	215.0
Do	Talona Creek	¼ mile above mouth	do	714.0

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ACCURACY OF STREAM MEASUREMENTS.—MURPHY

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

ACCURACY

OF

STREAM MEASUREMENTS

BY

EDWARD CHARLES MURPHY

WASHINGTON
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1902

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., December 30, 1901.

SIR: I have the honor to transmit herewith a manuscript prepared by Prof. E. C. Murphy, of Cornell University, Ithaca, N. Y., giving the results of investigations made by him into the accuracy of stream measurements as ordinarily conducted by the hydrographers of this Survey.

Professor Murphy was for some time resident hydrographer for eastern Kansas, and carried on in the field measurements of several rivers, being thus by actual practice thoroughly familiar with the operations of the hydrographic branch of the Geological Survey. Upon his removal to Ithaca Professor Murphy began a series of experiments, using the facilities offered by the hydraulic laboratory of Cornell University.

While the methods of river measurement at present in use are believed to be sufficiently accurate for the purposes of ascertaining the water resources of the United States, yet it is important to know their probable accuracy, and particularly the accuracy of the instruments which are commonly employed. Through such knowledge and experience gained from time to time it will be possible to improve upon the methods, in the interest of greater exactness or wider diffusion of the work.

I therefore request that this manuscript be published in the series of Water-Supply and Irrigation Papers.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

ACCURACY OF STREAM MEASUREMENTS.

By EDWARD C. MURPHY.

FACTORS CONTROLLING ACCURACY OF STREAM MEASUREMENTS.

The accuracy of a stream measurement depends largely upon the accuracy with which the cross-sectional area and the velocity are measured. There is no special difficulty in measuring the first factor, but the second factor—the velocity—is very difficult to measure, chiefly for the reason that it is constantly changing. It not only varies from the surface to the bottom and from one bank of the stream to the other, so that it is necessary to measure it at many points, but it is constantly changing at every point, even when the cross-sectional area and the discharge (and consequently the mean velocity) remain constant. Several experimenters have observed the phenomenon of "pulsation of moving water," and a few have tried to measure it, but as yet little is known of the magnitude and frequency of the pulsations or of the laws governing them. J. B. Francis says:[a] "It is observed that there is a continual change in all parts of these channels, although there may be no sensible change in the volume of water flowing and consequently in the mean velocity." Captain Cunningham says:[b] "One of the most important conclusions of modern experiments is that the motion of water, even when tranquil to the eye, is extremely unsteady, so that there is no definite velocity at any point, but the velocity varies everywhere, largely from instant to instant. * * * It is analogous to the unsteady motion of wind, which is exemplified by the swaying of wind vanes and by the fluttering of pinions." D. F. Henry says:[c] "All water in motion has an intermittent velocity, increasing and decreasing according to some undiscovered law," and Henry found this true of streams of all sizes, from small mill races to the great St. Lawrence River.

A knowledge of these phenomena is evidently of vital importance in making and computing stream measurements. If only a few observations of velocity are made, these may all, or nearly all, be

[a] Trans. Am. Soc. Civ. Eng., Vol. VII, p. 111.
[b] Recent Hydraulic Experiments: Proc. Inst. Civ. Eng., Vol. LXXI, p. 7.
[c] Jour. Franklin Inst., Vol. LXII, p. 323.

made at a time of maximum impulse, and thus the measured mean velocity be too large; or it is possible that most of the observations may be made at a time of minimum impulse, and thus the mean velocity be too small. They also have an important bearing on the kind of instrument best suited to measure the velocity, as some—the float rod, for example—give the velocity of a single impulse, while others, as the current meter, show the average velocity due to all the impulses during the observation.

The motion of water in an open channel is not, however, simply a succession of impulses. On the contrary, it is exceedingly complex, very different from the uniform flow in parallel straight lines that is assumed in deriving the common hydraulic formulæ. When closely observed the water of the most undisturbed streams is seen to "boil" and swirl and to be very unsteady, some particles moving up, others down, others across, but all as a rule having a general motion downstream.

The accuracy of a discharge measurement also depends much upon the physical features of the stream at the discharge section or point of measurement. When possible this section should be on a straight reach and far enough from a bend to be out of its influence, the bed should be permanent and not stony, and the slope and wetted perimeter such that at high and low stages of the stream the velocity in all parts of the section will be easily measurable. The banks should be sufficiently high not to be overflowed at flood stage, and the section should be free from the influence of milldams and bridge piers. In addition, economy requires that the section selected be easily accessible from a railway station and that there be a person living near who will read the elevation of the water surface at stated times. Seldom if ever are all of these conditions even approximately satisfied. Scour of bed in some cases and silting in other cases give much trouble; too great a velocity at high stages and too low a velocity at low stages to measure with accuracy are common difficulties; and milldams often give trouble, on account of storage and irregular discharge through their wheels; so that the hydrographer must make the most of the best location he can find, always having in mind the desirable and the undesirable qualities.

Rapid fluctuations of the water surface or river height during measurement and the condition of the velocity-measuring instrument are other factors which affect the accuracy of a stream measurement.

A great many discharge measurements of natural and artificial channels have been made with various kinds of instruments and in various ways. The earlier ones were made with crude instruments, and in some cases the surface velocity only was observed, the mean velocity being computed from a formula which we now know is not correct. Very little appears to have been done in the way of determining the degree of accuracy of the measurements. Even when the

experimenter has used two or more instruments to measure velocity, he does not appear to have made simultaneous measurements with different instruments, or employed different methods with the same instruments, in order to test the accuracy of the results.

These matters are all discussed in detail on the following pages.

METHODS OF MEASURING VELOCITY.

The methods that have been used for measuring velocity may be divided into two general classes—the direct and indirect. The direct methods include all ways of ascertaining the velocity of water from bodies floating in it, such as surface floats, float rods, double floats, etc. The indirect methods include measurements with the current meter, pressure plates, the thermometer, etc., by which the velocity of the water is inferred from its impact, its pressure, or its temperature. Measurements by the direct methods are simple, requiring only the measurement of the time that it takes a body in the water to move over a certain distance, while in the indirect methods the constant of the instant must first be found from experiment. The latter methods are, however, theoretically better than the former.

By the direct methods the mean velocity of a comparatively few particles of water is found for the time required for the float to move between the sections of observation—that is, the float is acted upon by the particles about it during the time it is passing over the measured distance. It is carried along by a single impulse of the water, and is not affected by the succeeding impulses, which may be greater or less than the impulse which moves it. Instruments of the second class, on the other hand—as, for instance, the meter—measure instantaneously the velocity of all the particles that strike it during the observation. If there were no pulsations of water, and if the particles following one another at any given point moved with uniform velocity, then the direct methods might, in the absence of wind, give good results; but since all moving water, even the most undisturbed, has these pulsations, velocity measurements by the indirect methods are decidedly more accurate than those by the direct methods. One measurement with a current meter is worth several measurements with floats.

There is another reason why indirect measurements are preferable to direct measurements. Since in the latter the mean velocity is found over a certain distance, usually from 50 to 200 feet, it is necessary to know the mean area over that distance, and this requires the measurement of many cross sections between the upper and the lower section, while by the indirect methods the measurement of only one area is required.

DIRECT METHODS.

SURFACE FLOATS.

Surface floats are small, light bodies, such as wood or wax, which float on the surface of the water and can readily be seen from the shore. Measurement by this means is rapid, but the velocities obtained may be greatly in error, due to the action of wind on the float. At best it only indicates the velocity for a short time of a comparatively few particles of water, and the mean velocity must be found from the relation between surface velocity and mean velocity, which is not well established. The time consumed by the floats in passing over a measured distance—usually from 50 to 200 feet—is observed, and the distance divided by the observed time gives the surface velocity at that point for that time.

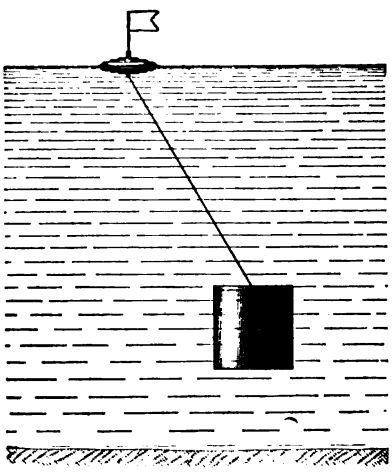

FIG. 1.—Double float used by Ellis in Connecticut River survey in 1874.

This method was used by Dubuat in 1779 in gaging the Canal du Jard, in France, and in 1782 in gaging the Haine River, Belgium; by Trechsel, in 1825, to gage the Outer Aar, near Thun; by Wampfler, in 1867, to gage the Simme Canal, Switzerland; by Harlacher, in 1881, to gage the Elbe, in Bohemia (at high water only); by Ellet, in 1858, in gaging the Ohio; and by others.

DOUBLE FLOATS.

The double float consists of a light surface float and a subsurface float somewhat heavier than water connected to it by a cord or a small rope. The office of the upper float is to support the lower float and indicate its position. The connecting cord can be lengthened at will and the lower float be placed at any desired depth. Fig. 1 shows the double float used by T. G. Ellis in the Connecticut River survey in 1874. This subsurface float was a hollow annulus of tin 8½ inches high, 8½ inches outside diameter, and 7½ inches inside diameter. Two brass wires were soldered across the bottom at right angles to each other, to which was attached 28 ounces of lead as a sinker. Two other wires were soldered at right angles to each other at the center, to which the connecting cord was attached. The surface float was an ellipsoid of tin 6 inches in diameter and 1½ inches thick, with a cork in the top holding a small flag and an eye in the bottom for the connecting cord. The connecting cord had a diameter of 0.036 inch.

The method of measuring stream flow by double floats as used by

Humphreys and Abbot in gaging the Mississippi River in 1851 and 1858 is substantially as follows:[a] A suitable place was selected on the river, a base line 200 feet long was measured off on one bank parallel to the axis of the current, and a section at each end of this base was marked out at right angles to it. The time consumed by each float in passing between these sections and the position of each float when it passed them were noted by four men, two at each end of the base, each party having a stop watch and a theodolite. At a signal from the engineer the floats were placed in the river from a boat about 100 feet above the upper section and were picked up by a man in a boat some distance below the lower section. At the instant a float passed the upper section a signal was given, the watches were started, and the angular position of the float was read with both theodolites. The instant the float passed the lower section a signal was again given, the watches were stopped, and the angular position of the float was again read with both theodolites. These readings gave the distance of the float from the base line when it passed the sections and two independent measurements of the time consumed by it in passing between the sections. Soundings were taken at the end sections and at one or more intermediate sections, from which the area of the mean section was computed.

In some cases where this method has been used the base was 300 feet long and the time of run of the floats has been recorded on a chronograph.

This method has its advantages and its disadvantages. In very deep rivers, such as the Mississippi, or in streams carrying weeds and grass, it is almost the only available method. Humphreys and Abbot, in their report on the Mississippi River, say:[b] "Saxton's current meter was tried but found to be unsuited to measurements in a river of such great depth and violence of current. Only double floats were found to give reliable results."

In regard to the disadvantages, D. F. Henry, who had charge of the field work of the gaging of the outlets of the Great Lakes and who has used this and other methods for deep rivers, says:[c] "All the objections to the surface float apply with greater force to the double float, and additional ones peculiar to itself." It is impossible to determine the exact position or depth of the lower float. Its position is determined from that of the surface float, but it varies with the direction and velocity of the wind and the length of the cord connecting the floats. The depth of the float is determined from the length of the connecting cord, but on account of the upward "boiling" motion of the water, and also the pressure of the water on a long connecting cord, the depth may be much less than the length of the cord. The upper float may drag the lower one or be dragged by it. At best

[a] Report on the Mississippi River, by Humphreys and Abbot, p. 224.
[b] Op. cit., p. 225.
[c] Jour. Franklin Inst., Vol. LXII, p. 167.

it can only give the velocity of a few particles for a short space of time.

This method of gaging was used in the Mississippi River and tributaries from 1857 to 1881. Since that time the current meter has been largely used. In 1869 it was used in conjunction with the current meter for gaging the outlets of the Great Lakes. It was also used by T. G. Ellis in 1874 in his survey of the Connecticut River, in conjunction with the current meter, and by Gordon in 1873 to gage the Irawadi River. For comparisons of accuracy of this method with others, see pages 47 to 51.

FLOAT RODS.

Professor Cabeo[a] was the first to use the float rod for measuring velocity. This was in 1646. The rod is of wood or tin, from 1 to 2 inches in diameter, weighted at the lower end so as to float vertically. Its lower end should nearly touch the bottom and its upper end project a few inches above the surface of the water, so as to be visible. The method of using float rods as followed by the writer in 1900 in the New York State canal survey is as follows: Two surveyor's 100-foot chains were stretched across the canal from 10 to 30 feet apart and at right angles to the axis of the canal. Fifteen feet above the upper chain a rope was stretched across the canal, and to this a boat was attached by pulleys, so that a man in the boat could easily move himself back and forth by pulling on the rope. Another rope was stretched across the canal from 6 to 8 feet below the lower chain and a boat operated from it in a similar way. The floats were put in by the man in the upper boat, two at a time and about 5 feet apart, and were observed by him until they passed the upper chain, when he called to the recorder the position of each. As they passed under the lower chain the man in the lower boat called out their position, and when they reached his boat he took them out of the water and brought them to the shore. An observer with two stop watches noted the time of passage of each pair of floats between the chains. A short run was used on account of the low velocity of the water.

The advantages and disadvantages of the method may be summed up briefly as follows:

Advantages.—For artificial channels of moderate and uniform depth and with floating grass and weeds this is probably the best method to use. The advantages of float rods as given by Captain Cunningham, who has used them to a large extent in his gagings of the Ganges Canal, are as follows:[b] (1) They interfere less with the natural motion of the water; (2) they measure velocity direct; (3) they can be used in a stream of any size; (4) they are not affected by silt and weeds; (5) they measure forward velocity; (6) they can be made by a common workman; and (7) they are cheap.

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[a] See Report of New York Barge Canal, 1901, p. 869.
[b] Proc. Inst. Civil Eng., Vol. LXXI, p. 1.

Disadvantages.—The rods are affected to some extent by wind; they do not give mean velocity, but velocity of impulses; they can not be used in deep streams or in streams of rough or irregular bed, and they are expensive to operate.

Float rods have been used by Cunningham, on the Ganges Canal, in 1880; by Francis, in 1852, on a canal at Lowell, Mass.; by Buffon, on the Tiber River, in 1821; by Krayenhoff, on the Rhine, in 1812; and by the Mississippi River Commission, on the Upper Mississippi, in 1881.

FLOAT FRAME.

Hirn used, for obtaining velocity, a light frame of wood which nearly filled the cross section of the channel, but there are practical difficulties in the way of the use of this instrument.

INDIRECT METHODS.

The following instruments and methods have been used at one time or another for measuring velocity indirectly. Several of them are now of historical interest only.

FLOAT WHEEL.

The float wheel was used by Borda and Dubuat for measuring surface velocities. That used by the latter was 2 feet in diameter, and recorded the revolutions on dials.

PRESSURE PLATE.

In 1779 Gaunthy invented the pressure plate, which consists of a disk of metal opposed to the pressure of water, the velocity being computed from the weight necessary to keep it vertical. The tachometer used by Brünings to gage the Rhine and the one used by Racourt in his gagings of the Neva were made on this principle. Captain Boileau also used a pressure plate in his tachometer.

BOX WITH HOLE IN SIDE.

A box with a hole in the side was used by Grandi in 1730 to measure velocity. It was lowered gradually from the surface to the bottom and raised again at the same rate, the velocity being inferred from the amount of water in the box.

HYDROMETRIC TUBE.

This instrument was used by Captain Boileau in 1850. It consists of a glass tube suspended in a frame, having a full-sized opening at one end and a small opening at the other end. The tube is filled with water and a bubble of air, and is placed in the water with the small end upstream. The large end is then opened and the time required for the bubble to traverse the tube is noted. From this time and the areas of the ends of the tube the velocity is computed.

HYDROMETRIC PENDULUM.

This instrument was used by Castelli in 1628. It consists of a ball suspended from the center of a graduated arc. The velocity is computed from the weight of the ball and the angle of the string when the water impinges on it.

THERMOMETER.

Leslie used a thermometer for measuring velocity. The principle of this method is that the temperature of water in motion is greater than the temperature when at rest.

PITOT TUBE.

This instrument was invented by Pitot in 1730. Fig. 2 shows it as improved and used by Darcy and Bazin.[a] It consists essentially of two tubes, one drawn to a fine point and pointing upstream, the other straight and with an opening at the lower end the size of the tube. The air in both tubes is partly exhausted, so that the water columns will rise to a convenient height. The velocity is found from the difference in the readings of the water columns. Like floats, this is an impulse-measuring instrument, but in using it both maximum and minimum impulses are observed and a mean is found. After the instrument is in place and the stop cocks R and R' are opened one of the observers applies his mouth to the tube O, removes the air until the surface of the water in the tubes stands at a convenient height to read, and then closes the upper cock (R). He observes the columns until they reach a maximum height, when he closes the cock R' and reads the surface of both columns; then he opens the cock R and observes the surface of both until the columns reach a minimum position, when he closes cock R' and reads both surfaces again. He now has a maximum and a minimum reading of each column, from which he makes the following deduction: If a' is the maximum reading of column A, and b' is the maximum reading of column B, and a'' is the minimum reading of column A, and b'' is the minimum reading of column B, then $a'-b'=d'$, the difference for the maximum impulse, and $a''-b''=d''$, the difference for the minimum impulse, and $\frac{d'+d''}{2}$ is the mean difference of the column readings for the two impulses. Two or three sets of these readings are taken at each point. Then if $\Sigma\frac{d}{2}$ is the mean of the values of these column differences ($\Sigma d= d'+d''+ \ . \ . \ . \ $), the velocity at that point is given by the formula $V=c\sqrt{2g\Sigma\frac{d}{2}}$, c being the coefficient found by rating and g the accel-

[a] Recherches hydrauliques, entreprises par M. H. Darcy continuées par M. H. Bazin. Première partie de Recherches expérimentales sur l'écoulement de l'eau dans les canaux découverts: Extrait des Mémoires présentés par divers savants à l'académie des sciences de Institut Impérial de France, Paris, 1865, Vol. XIX, Pl. XVII, fig. 5.

eration of gravity. The velocity can very quickly be found by one accustomed to using the instrument. The accuracy of V depends on that of c and on $\sqrt{\Sigma d}$, the greater the number of d's, or sets of observations, the more nearly accurate will be the value of V.

CURRENT METER.

The current meter had its beginning in the float wheel used by Borda and Dubuat to obtain surface velocities. In 1790 Waltman modified this wheel so that it could be used below the surface. His meter had helicoidal blades and an endless screw on its axis, which by gearing into a train of wheels caused a record of the number of revolutions of the wheel to be made on dials. It was moved up and down on a rod the lower end of which was driven firmly into the river bed. The recording apparatus was thrown in or out of action by a pull on a string. It was necessary to lift the meter to the surface to read the revolutions, which was a great drawback to its use, as was also the fact that dirt in the water retarded the train of wheels. Lepont sought to remove these difficulties by bringing the recording apparatus to the surface, away from the dirty water and where it could be read without lifting the meter. He did this by introducing a

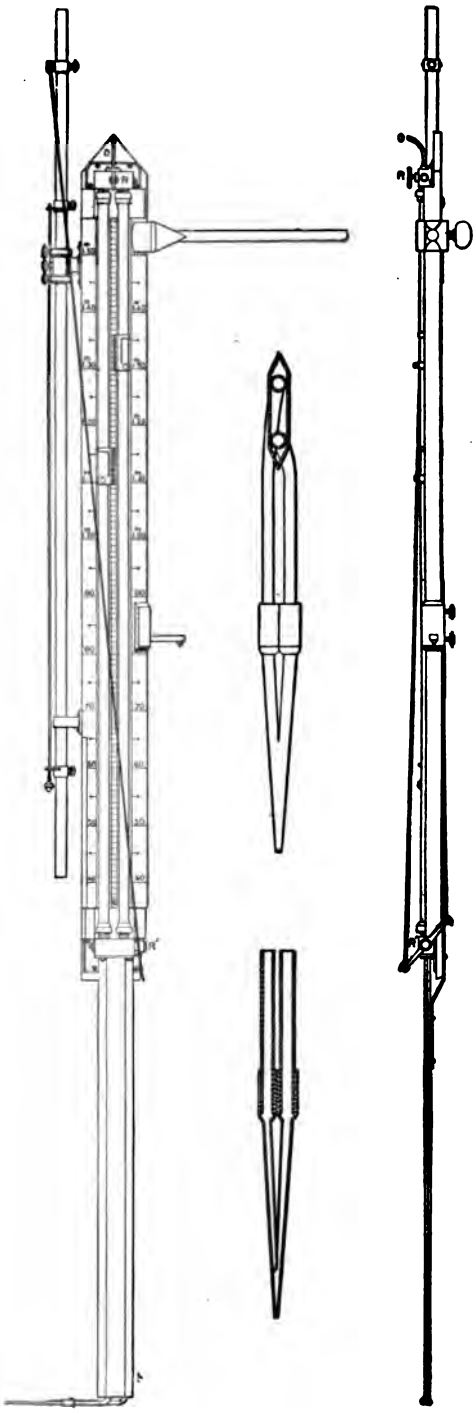

FIG. 2—Pitot tube.

vertical shaft or rod with beveled gearing, but this increased the friction so that it could only be used in shallow water. Baumgarten, Saxton, and others following modified its form somewhat, but did not materially improve it. Brewster made one in which the axis of the meter was a long screw and the revolutions were given by the distance the wheel traveled along this screw. The friction was thus

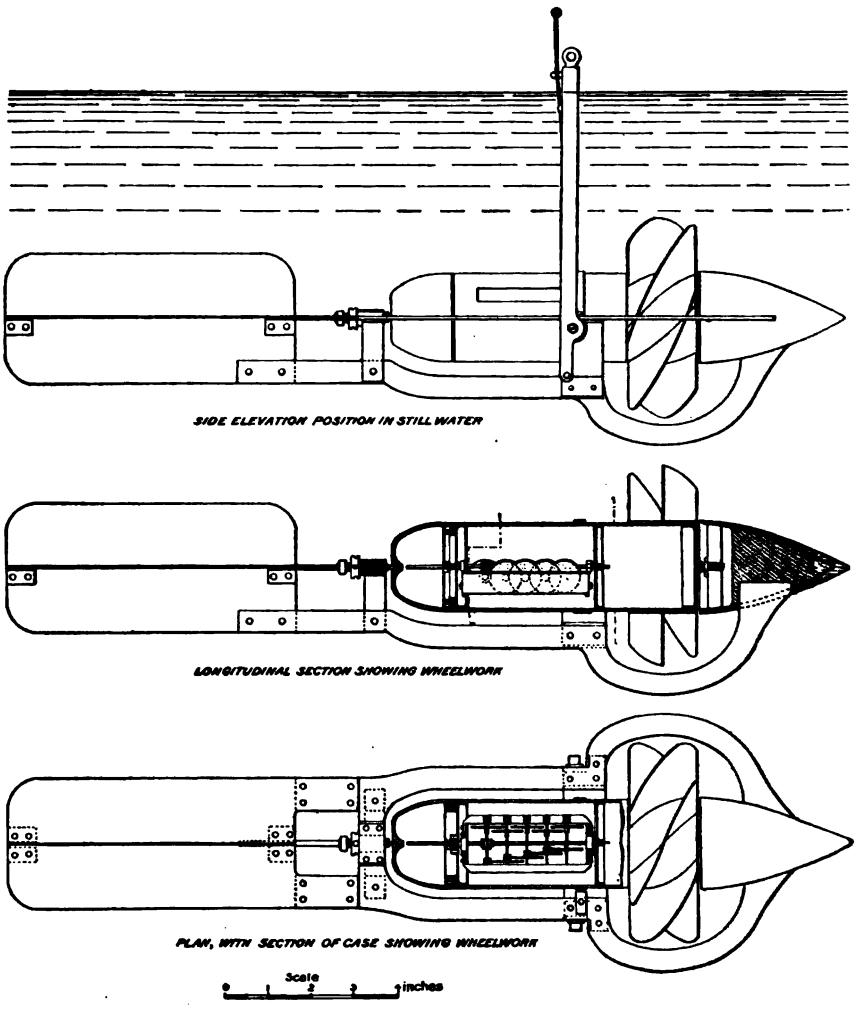

FIG. 3.—Moore current meter.

lessened, but the meter had to be stopped before the wheel traveled the whole length of the screw. It was a long step in advance that was taken by D. F. Henry when he applied an electric recording device to the meter, for by it the difficulties that Lepont and others sought to avoid are very successfully overcome, the friction of the train of recording wheels being entirely done away with. If a recording device

PRICE ELECTRIC CURRENT METERS.

is used it is worked by a spring and not by the meter, and, furthermore, it is not necessary to lift the meter to the surface to read the number of revolutions, which are recorded electrically, or may be

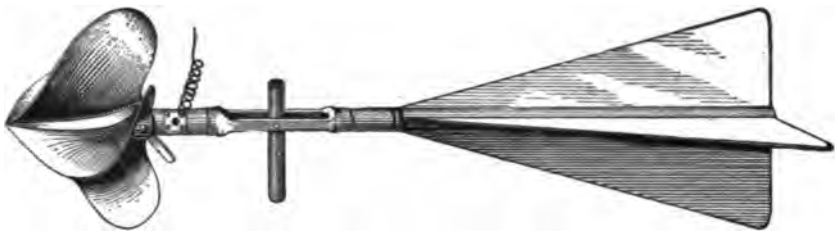

FIG. 4.—Haskell current meter.

counted from the indications of a buzzer. The electric meter as used by Henry is shown in fig. 10, page 34; that used by Moore in fig. 3.

Meters in use at the present day may be divided into two classes: (1) Those in which the revolving part turns about a horizontal axis, and (2) those in which it revolves about a vertical axis. The former class is illustrated by the Haskell and Fteley meters, shown in figs. 4 and 5, respectively, and the latter class by the Price meter, shown in Pl. I. Meters of the latter class have some advantages over those of the former class: First, friction is usually less, since it nearly all comes on one point, and this point can be protected from the action of grit in the water and from jars; and, second, for a given high velocity the wheel will not revolve as rapidly as the wheel of a meter of the first class under the same conditions, and at the same time the wheel will start in a less velocity than will the wheel of a meter of the former class, so that both low and high velocities can be measured more accurately with meters of the second class than with those of the first class. For example, by comparing the rating table of Haskell meter No. 3 on page 81 with that of small Price meter No. 363 on page 42, we find that the former requires a velocity of about 0.20 foot per second to start it, and that it makes 6.5 revolutions per second in water having

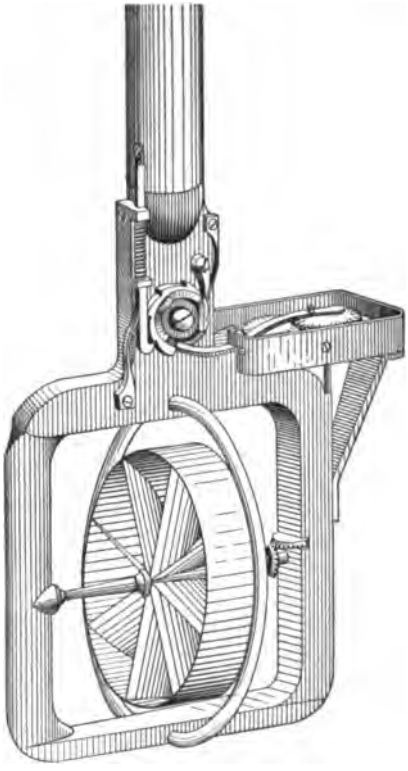

FIG. 5.—Fteley current meter.

a velocity of 7 feet per second, while the latter requires a velocity of about 0.06 foot per second to start it and makes only 3.02 revolutions in water having a velocity of 7 feet per second. A rate of 3 revolutions per second can easily be recorded or counted, but a rate of 6.5 revolutions per second can not be counted or easily recorded.

The disadvantages of the current meter are, briefly, as follows: (1) It can not be used where there is much floating grass or weeds, as on canals where the weeds are cut and allowed to float in the water, float rods being much better in such cases; (2) it requires rating before use and frequently thereafter; and (3) it must be used with care. These last two conditions, however, are true for all instruments used for measuring velocity indirectly.

The meter without some electrical device for indicating to the observer the revolutions in a given time, and which must be lifted out of the water to read the revolutions, is a thing of the past. Too much time is lost in making the readings. The acoustic meter is not a success. The clicks are not sufficiently loud to be heard when the water is deep and the place noisy.

The advantages of the meter are as follows: (1) It gives integrated or mean velocity (any kind of a float gives the velocity of a comparatively few particles at some stage of a pulsation of the water, not mean velocity); and (2) it can be used on streams of all sizes.

For large streams the choice of instruments is between the current meter and the double float, and the meter is preferable except where a large amount of weeds and grass is carried along in the water. For artificial channels the choice is between the meter and the float rod, and the meter has the preference except where there is a considerable amount of floating weeds, and possibly for very slow velocities also, but the latter is still in doubt. For velocities of 0.25 foot per second the meter will give the mean velocity as accurately and more rapidly than the rods, and at least four persons are necessary with the rod method, whereas one person, or at most two persons, can make the gaging with the meter, and the expense of moving the equipment from place to place is much greater for the rods than for the meter.

SLOPE FORMULA.

The velocity of a stream can be computed from measurements of the slope of the surface, the dimensions of the cross section, and a knowledge of the roughness of the bottom and sides. The formula which is now almost universally used for this purpose was devised by Kutter in 1869[a] and is as follows:

$$V=\left[\frac{41.6+\frac{1.811}{n}+\frac{.00281}{s}}{1+\left(41.6+\frac{.00281}{s}\right)\frac{n}{\sqrt{Rs}}}\right]\sqrt{Rs}$$

[a] Flow of Water in Rivers and Other Channels, by E. Ganguillet and W. R. Kutter.

In this formula V=velocity, in feet per second; s=surface slope=$\frac{h}{l}$, h being the fall of the surface in the distance l; R=hydraulic radius=$\frac{F}{w}$, F being the cross-sectional area and w the wetted perimeter; and n a ratio whose value varies from 0.009 for a well-planed wooden channel to 0.035 for a channel overgrown with weeds or covered with stones.

This formula is said to apply to streams of all sizes, from creeks and sewers to large rivers like the Mississippi, its constants being determined from Bazin's gagings of small channels, from Humphreys and Abbot's gagings of the Mississippi River, from Cunningham's gagings of the Ganges Canal, and from gagings by many others.

The disadvantage of the method is that it is very difficult to measure accurately the surface slope (s) of large rivers. T. G. Ellis says[a] that on the Connecticut River the slope of parts 100 to 400 feet long was very carefully measured and the discharge computed, using the best modern slope formulæ. The discharge found from these formulæ differed by 50 to 250 per cent from that found by gaging. He thinks the slope is so uncertain an element that slope formulæ are of little value. Captain Cunningham, after an examination of five hundred slope measurements of the Ganges Canal, says:[b] "It [the slope of surface measurement] is so delicate a matter that the results are of doubtful use." He found that the slope was very different at different parts of a reach from 1 to 2 miles long, and that the slope at opposite sides differed 50 per cent. Ellet says,[c] in regard to the slope of the Mississippi River: "It not unfrequently happens that while the mass of the water which its channel bears is sweeping to the *south* at a speed of four or five miles per hour, the water near the shore is running *to the north* at a speed of one or two miles per hour. It is no unusual thing to find a swift current and a corresponding fall on one shore toward the south, and on the opposite shore a visible current and an appreciable slope toward the north."

Only in very rare cases is it advisable to use this method.

MEASUREMENT OF SURFACE FLUCTUATIONS.

Any change in the elevation of the surface of a stream affects the discharge in two ways: The cross-sectional area is changed and as a rule the velocity also is changed.[d] It is necessary, therefore, in accurate work to measure the surface fluctuations with great care. Wave action, due to wind or other causes, should be eliminated.

[a] Trans. Am. Soc. Civ. Eng., Vol. XI, p. 23.

[b] Proc. Inst. Civ. Eng., Vol. LXXI, p. 11.

[c] Report on the Mississippi River, by Humphreys and Abbot, p. 218.

[d] On some streams there are places where the mean velocity remains nearly constant for several feet variation in stage of river. This is true of the Verdigris River at Liberty, Kans. See Nineteenth Ann. Rept. U. S. Geol. Survey, Pt. IV, p. 374.

There are two classes of instruments in use at the present time for indicating surface elevations: (1) Self-registering gages, which give a continuous record of the changes in surface elevation; and (2) a fixed scale from which the elevation of the surface is read at any time, or a moving scale with a fixed index from which the elevation of the surface is read.

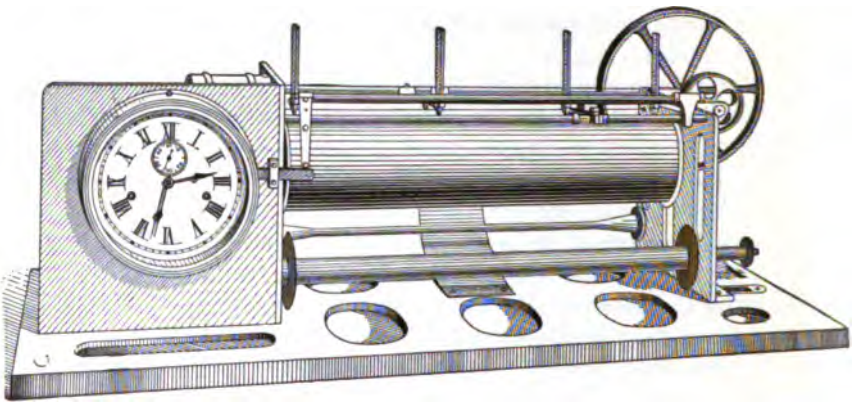

FIG. 6.—Self-registering water gage used by United States Lake Survey.

The United States Lake Survey self-registering water gage, shown in fig. 6, is a good illustration of instruments of the first class. The center pen is connected to a float on the surface of the lake, and its

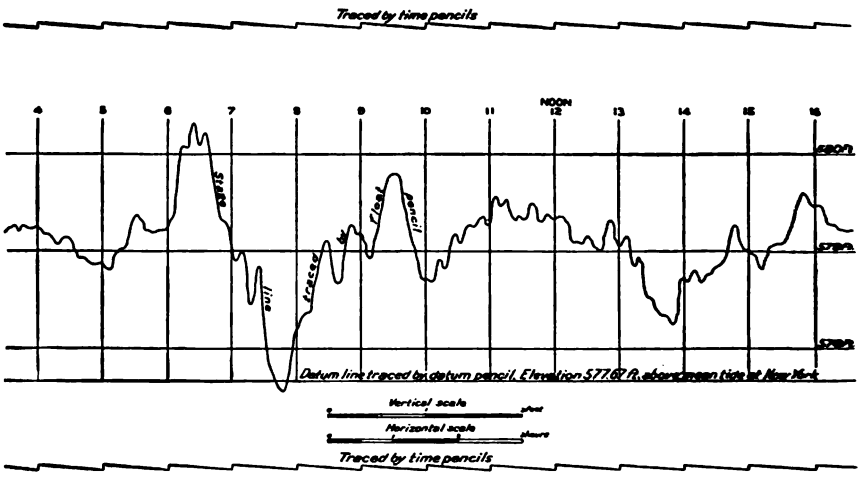

FIG. 7.—Record made by self-registering water gage used by United States Lake Survey.

motion is proportional to the change in elevation of the float. This motion is traced by the pen on a sheet of paper on the drum, which is moved at a uniform rate by clockwork. The two outer pens record the time. Fig. 7 is a reproduction of the record made by this instrument on May 17, 1899. The elevation of the surface at any instant is

given by the corresponding ordinate of this curve. This figure illustrates the need of an accurate record of the change in stage, for it shows a change of surface elevation of 2.5 feet in one and five-tenths hours.

The hook gage, shown in fig. 8, is a good illustration of a gage of the second class. The frame is fastened firmly to a post in the water, and the elevation of the zero reading is determined. By turning the milled nut the hook is raised until its point comes to the surface of the water. This can be done very accurately in still water, by means of the little spot of light on the point of the hook. The scale is then read, and from it the surface elevation is found.

The water gage used by the United States Board of Engineers on Deep Waterways in 1897–98, on the Niagara River at Buffalo, N. Y., was of the box-with-float type. The box was of wood, 7 inches high, 7 inches wide, and 7 feet long, with a closed bottom and a removable cover. The box was fastened firmly in the water, with half its length below the surface. Water was admitted to it through one or more of three ¼-inch holes, allowing the float to change its elevation as the river stage changed and at the same time eliminating the effect of waves. The float was a 2-quart bottle with a 7-foot staff, marked to feet, tenths, and hundredths, wedged into it. This staff extended up through the cover, and was marked so as to give the rise of the water surface above a certain plane as read at the cover of the box.

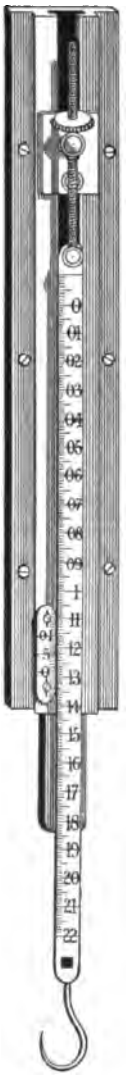

FIG. 8.—Hook gage for measuring surface fluctuations.

VERTICAL VELOCITY CURVES.

The relation between velocity and depth in a vertical section of a stream parallel to the thread of the current, or the vertical velocity curve, is very desirable. From such a curve the ratio of velocity at any depth to mean velocity can easily be found and the discharge be computed from observations at one depth only in verticals.

Much effort has been expended in investigating this relation and the change in it for change in river stage. As might be expected, the results of experiments in this direction do not agree. Each investigator adopts a new form of curve to fit his observations. In 1791 Waltman made some observations on the Rhine, from which he concluded that the vertical velocity curve is a reversed parabola with its vertex below the bed of the river. In 1820 De Fontaine found the greatest velocity of the Rhine to be at

the surface. He states that two inclined right lines intersecting about mid depth satisfy his vertical-curve observations. In 1824–1826 Racourt made observations on the Neva River, from which he concluded that this curve is an ellipse whose minor axis is a little below the surface. Funk adopted a logarithmic curve for his observations on the Weser in 1820. In 1844 Boileau found this curve for a small canal to be a parabola with its axis near the surface. Darcy and Bazin found it to be a reversed parabola for their experiment canal, the perimeter changing with the character of the bed. For the Mississippi River, Humphreys and Abbot found it to be a parabola whose axis is three-tenths depth below the surface. Henry found it to be an ellipse for the St. Clair River, while Baumgarten says that no simple curve will fit the observations in a vertical. From the results of these investigations and others that might be mentioned it appears that the shape of the vertical velocity curve depends much on local conditions, as roughness of bed, slope, ratio of depth to width, wind, obstructions, etc. Two facts must be borne in mind, however: (1) All the vertical velocity-curve observations obtained with a single meter will not when plotted fall on any one line, but the results will be scattered more or less, and it will be possible to pass a number of curves among them, one satisfying the observations about as well as another; and (2) there is some part of each of the curves mentioned which if placed by the side of some part of another curve will coincide with it closely, so that it is quite possible for any or all of these curves to fit more or less closely a set of imperfect vertical velocity-curve observations.

There are two methods of obtaining vertical velocity curves with current meters: (1) The single-meter method, and (2) the multiple-meter method. In the former a meter is held at as many points in a vertical as desired—at each tenth of the depth, for example—for a time sufficiently long to eliminate the effect of pulsations. This requires one or more hours to a vertical, during which time a permanent change may occur in the mean velocity. In the latter method, however, this difficulty is overcome, for enough meters are used simultaneously to give the whole curve in one operation.

In the vertical velocity-curve work on the St. Clair River, under the direction of E. E. Haskell, United States assistant engineer, eleven meters were used at a time. These were fastened between two cables, which were attached to a 200-pound sinker at the lower end and to a drum at the upper end, and operated from a catamaran. The lower meter was 1.75 feet above the bottom; the other ten were placed at each tenth of the depth. Each meter was connected with an electric register, and by means of a switch all of the circuits could be opened in one operation. The observer, with a stop watch in one hand and the switch handle in the other, started the watch and at a given instant closed all of the circuits through the meters and registers. At the end of the observation he stopped the watch and opened the circuits

at the same instant. One observation of six hundred seconds was made with the meters arranged as described, and from one to ten others of one hundred seconds each with the meters arranged in other ways in each vertical.

There should be some criterion for the rejection of doubtful observations and the grouping of vertical velocity curves. The following table gives the position of the vertex of sixty-nine vertical velocity curves obtained on the Mississippi River by Humphreys and Abbott, and illustrates this need:

Table showing position of vertex of vertical velocity curves obtained on Mississippi River.

Depth.	First series.		Second series.		Total.	
	Number of verticals.	Number of floats.	Number of verticals.	Number of floats.	Number of verticals.	Number of floats.
Surface	12	63	8	17	20	80
One-tenth	11	46	1	2	12	48
Two-tenths	5	33	.....	.....	5	33
Three-tenths	3	20	1	3	5	23
Four-tenths	.....	.....	4	9	4	9
Five-tenths	2	22	1	3	3	25
Six-tenths	5	30	1	3	6	33
Seven-tenths	.....	.....	6	18	6	18
Eight-tenths	.....	.....	6	15	6	15
Nine-tenths	.....	.....	2	5	2	5
Bottom	1	8	.....	.....	1	8
Sum	39	222	30	75	69	297

The vertex of 34 per cent of the curves in the foregoing table is at or below mid depth of the river. Using all of them the vertex is three-tenths depth below the surface. This combination of curves so dissimilar is, to say the least, very questionable. Those in which the vertex is at or below seven-tenths depth should be rejected, or at least not combined with the others, for they are due either to errors or to abnormal conditions, and should not be used in deriving a general law.

Vertical velocity curves obtained in different parts of the discharge section for different depths are frequently combined by combining the velocities at each tenth of the depth. This assumes that the curves are similar in all parts of the discharge section, which is not true except in rare cases.

There is very little available data on the change in the vertical velocity curve with change of river stage. In the data on this point that have come to the writer's observation the change in stage is small and the inference to be drawn not conclusive. The effect of roughness of bed decreases, while that of slope and hydraulic radius increases with increase of stage. The effect of these on the shape of the curve can only be determined by careful measurements in which there is a wide range of stage.

PULSATION OF MOVING WATER.

We have already called attention to the fact that one of the reasons it is difficult to measure accurately the velocity of water is that the velocity at any given point in a stream is constantly changing. This is true of both natural and artificial channels of all sizes. Captain Cunningham, who observed this pulsation of moving water in his experiments on the Ganges Canal, of India, states that he considers fifty repetitions with float rods necessary in order to get a good average value of the velocity in one vertical of a canal.[a] J. B. Francis has made numerous measurements of the velocity with float rods in a rectangular wooden flume at Lowell, Mass., every precaution being taken to have the usual causes of irregularity of motion suppressed. The time of run was obtained by the use of an electric telegraph and a chronograph, and the depth was very carefully measured with a hook gage, and yet he found that the velocity shown by these floats varied from 8.57 per cent above the mean to 11.4 per cent below it. He says: "Similar and probably greater variations occur in different parts of the depth from the same cause."[b] Adam Baum has made some observations on the variation of velocity in the Rhine near the Bridge of Constance.[c] He fixed a current meter in the river and noted the time of each 100 revolutions of the meter wheel for a period of two hours. The results show a continual change in the velocity for a constant depth of water. He concludes that for an accurate measurement of velocity it is necessary to extend the observations over a period of one hour at each point.

Professor Unwin has made some observations with a current meter on the variation in velocity in the river Thames.[d] He noted the time of each 100 revolutions, and upon plotting the time and the revolutions found that they gave a very irregular curve. The mean of each 500 revolutions, however, when plotted with the corresponding time gave a rather regular curve. The following are some of the results of Professor Unwin's observations:

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[a] Proc. Inst. Civ. Eng., Vol. LXXI, p. 8.
[b] Trans. Am. Soc. Civ. Eng., Vol. VII, p. 117.
[c] Proc. Inst. Civ. Eng., Vol. LXXI, pp. 456-459.
[d] Op. cit., pp. 348, 349.

Variation in velocity at three points of a vertical of Thames River as found by Unwin.

At 0.5 meter depth; velocity found from—		At 3 meters depth; velocity found from 100 revolutions.	At 6 meters depth; velocity found from 100 revolutions.	Variation $\left(\frac{V_m - V}{V_m}\right)$.[a]		
100 revolutions.	500 revolutions.			At 0.5 meter depth.	At 3 meters depth.	At 6 meters depth.
Met. per sec.	*Met. per sec.*	*Met. per sec.*	*Met. per sec.*	*Per cent.*	*Per cent.*	*Per cent.*
1.909	1.877	1.861	1.111	−1.8	+6.6	− 3.6
1.942	1.846	2.030	1.069	−3.6	−1.9	+ 0.3
1.967	1.846	1.942	0.977	−6.0	+2.6	+ 8.9
1.942	1.846	2.030	1.180	−3.6	−1.9	10.1
1.861	1.832	2.030	1.044	+0.7	−1.9	+ 2.6
1.861	1.832	2.060	0.937	+0.7	−3.4	+ 12.6
1.887	1.823	1.909	1.021	−0.7	+4.2	+ 4.8
1.861	1.787	1.909	0.998	+0.7	+4.2	+ 7.0
1.861	1.809	1.861	0.977	+0.7	+6.7	+ 8.9
1.861	1.787	2.030	1.094	+0.7	−1.9	− 2.1
1.942	1.861	2.125	0.900	−3.6	−6.7	+16.1
1.760	1.823	2.030	1.094	+6.1	−1.9	− 2.1
1.831	.....	2.086	1.021	+2.4	−4.7	+ 4.7
1.719	.....	1.994	1.180	+8.3	0.0	−10.1
1.942	.....	2.086	1.079	−3.6	−4.7	− 0.7
1.831	.....	1.909	1.472	+2.4	+4.2	−37.4
1.875		1.993	1.072			

[a] V = velocity, V_m = mean velocity.

It is seen that during the period required for the meter to make 1,600 revolutions the greatest variations from the mean velocity at 0.5 meter depth are +8.3 per cent and −6 per cent and at 6 meters depth +16.1 per cent and −37.4 per cent. The greatest difference in velocity, as shown by two consecutive 100-revolution periods, is 12 per cent at 0.5 meter depth and 36.7 per cent at 6 meters depth. A velocity measurement of 100 revolutions 0.5 meter below the surface may be in error 8 per cent and one 6 meters below may be in error 37 per cent.

D. F. Henry[a] has observed this fluctuation in velocity at a given point in large and in small streams. He says: "The lesser fluctuations have a duration of 30 to 60 seconds and the larger ones from 5 to 10 minutes. They do not seem to be synchronous with the surface fluctuations, and are smaller at the surface than at the bottom."

Harlacher[b] found the velocity near the surface of the Rhine to vary 20 per cent in a few seconds, and near the bottom he found it to vary 50 per cent in the same period.

Marr's simultaneous observations of velocity in the Mississippi River at Burlington, Iowa,[c] with five current meters are described on page 48. The following table gives the velocity, as shown by two of his current meters, one near the surface and the other near the bottom, for consecutive periods of one minute each. The depth in

[a] Jour. Franklin Inst., Vol. LXII, p. 323.
[b] Trans. Am. Soc. Civ. Eng., Vol. XII, p. 311.
[c] Report on Current Meter Observations, Burlington, Iowa, by Maj. A. McKenzie, 1884.

the first section is 11 feet, in the second section 27.6 feet, and the meter is 4 feet above the bottom:

Variation in velocity per minute in Mississippi River at Burlington, Iowa.

Simultaneous observations in section No. 1.				Simultaneous observations in section No. 2.			
Velocity 1 foot below surface (V).	Variation $\left(\frac{V_m-V}{V_m}\right)$.	Velocity 9.1 feet below surface (V_m).	Variation $\left(\frac{V_m-V}{V_m}\right)$.	Velocity 3.6 feet below surface (V).	Variation $\left(\frac{V_m-V}{V_m}\right)$.	Velocity 23.6 feet below surface (V_m).	Variation $\left(\frac{V_m-V}{V_m}\right)$.
Ft. per sec.	*Per cent.*	*Ft. per sec.*	*Per cent.*	*Ft. per sec.*	*Per cent.*	*Ft. per sec.*	*Per cent.*
2.242	+2.0	1.724	0.0	2.286	+4.8	1.966	+ 2.4
2.267	+0.9	1.675	+ 2.9	2.353	+1.3	1.817	+ 9.8
2.252	+1.1	1.761	− 2.2	2.437	−2.3	1.985	+ 1.5
2.236	+2.2	1.744	− 1.2	2.300	+3.5	2.008	+ 0.3
2.267	+0.9	1.797	− 4.3	2.404	−0.9	2.065	− 2.5
2.299	−0.5	1.766	− 2.4	2.378	+0.2	2.119	− 5.2
2.289	0.0	1.772	− 2.8	2.414	−1.3	1.926	+ 4.4
2.274	+0.6	1.819	− 5.5	2.392	−0.4	2.008	+ 0.3
2.211	+3.3	1.712	+ 0.7	2.313	+3.0	1.983	+ 1.5
2.224	+2.8	1.644	+ 4.7	2.296	+3.8	2.081	− 3.3
2.280	+0.3	1.698	+ 1.5	2.383	0.0	2.104	− 4.5
2.239	+2.1	1.915	−11.1	2.397	−0.6	2.276	−13.3
2.280	+0.3	1.670	+ 3.1	2.420	−1.6	2.092	− 3.9
2.289	0.0	1.775	− 3.1	2.361	+0.9	2.008	+ 0.3
2.321	−1.5	1.582	+ 8.3	2.278	+4.4	2.047	− 1.6
2.420	−6.0	1.664	+ 3.5	2.445	−2.6	1.848	+ 8.3
2.445	−6.9	1.741	− 1.0	2.459	−3.2	2.024	− 1.0
2.308	−0.9	1.717	+ 0.5	2.428	−1.9	2.070	− 2.8
2.333	−2.0	1.800	− 4.4	2.456	−3.1	1.796	+10.8
2.264	+1.0	1.695	+ 1.7	2.460	−3.2	2.055	− 2.4
2.327	−1.3	1.812	− 5.1	.....	.....	.....	.....
2.311	−1.0	1.689	+ 2.0	.....	.....	.....	.....
2.305	−0.8	1.792	− 4.0	.....	.....	.....	.....
2.311	−1.0	1.627	+ 5.7	.....	.....	.....	.....
2.277	+0.4	1.554	+ 9.9	.....	.....	.....	.....
2.274	+0.6	1.678	+ 2.7	.....	.....	.....	.....
2.292	−0.2	1.731	− 0.4	.....	.....	.....	.....
2.271	+0.7	1.704	+ 1.1	.....	.....	.....	.....
2.321	−1.5	1.698	+ 1.5	.....	.....	.....	.....
2.261	+1.1	1.723	0.0	.....	.....	.....	.....
2.217	+3.6	1.757	− 1.9	.....	.....	.....	.....
2.280	+0.3	1.743	− 1.1	.....	.....	.....	.....
2.287	.....	1.724	.....	2.383	.....	2.014	.....

It is seen that in the first section the greatest departures of velocity from the mean are +3.6 per cent and −6.9 per cent at 1 foot below the surface, and +9.9 per cent and −11.1 per cent at 9.1 feet below the surface, or 2 feet above the bottom. The greatest difference in velocity obtained from two consecutive 1-minute periods is 6 per cent at 1 foot below the surface and 12.5 per cent at 9.1 feet below the surface, or 2 feet above the bottom. In the second section the greatest departures of velocities from the mean are +4.8 per cent and −3.2 per cent at 3.6 feet below the surface, and +10.8 per cent and −13.3 per cent at 23.6 feet below the surface, or 4 feet above the bottom. The greatest difference in velocity obtained from two consecutive 1-minute periods is 7 per cent at 3.6 feet below the surface and 13.6 per cent at 4 feet above the bottom. In the first section a velocity measurement near the surface may be in error 7 per cent and a measurement 2 feet above the bottom may be in error 11 per cent. In the second section a velocity measurement 3.6 feet below the surface may be in error 4.8 per cent and a measurement 4 feet above the bottom in error 13.3 per cent.

In 1899, w. ⌣ measuring the discharge of the St. Clair River, Mr. L. C. Sabin, assistant engineer, made some experiments to determine the pulsations or fluctuations in the velocity of the river at the discharge station. Four meters were used, placed 50 feet apart and at the same depth. In the first series of observations the meters were in a line across the river and at right angles to the current; in the second series they were in a line with the axis of the current. Simultaneous readings of the four meters were taken every fifteen seconds for several periods of ten minutes each. The results were plotted, using time as abscissæ and velocity as ordinates, and a curve drawn for each meter, showing the fluctuations in velocity in each fifteen seconds of time at four points 50 feet apart. These curves have two sets of waves—small ones of fifteen to sixty seconds amplitude and larger ones of three to six or more minutes amplitude. The range of velocity as found from the large waves is in some cases 35 per cent of the mean velocity shown by the meter for ten minutes. The curves for two adjacent meters are at times nearly parallel, but they soon diverge and cross each other occasionally. The curves for the meters in a line with the axis of the river resemble one another more closely and are more nearly parallel than those of the meters in a line across the river. These experiments indicate that the pulsations are very limited in extent in a direction at right angles to the current, but that they can be traced for some distance in the direction of the thread of the current. The whole depth of the river is affected by them, and their effect decreases from the bottom toward the surface.

The practical lesson to be drawn from the experiments by Sabin and others is that velocity observations of short duration are of little value unless they are numerous and well distributed over the discharge area. In order to eliminate the effect of the pulsations, each observation should extend over a period of from six to ten minutes. Long single observations and rapid fluctuations of water surface elevation require that discharge be found from single observations in comparatively few verticals, and that the ratio of velocity at this depth to mean velocity be known from vertical velocity curves. This emphasizes the need of a thorough investigation of the relation between velocity and depth in a vertical longitudinal plane and the change in this relation with change of river stage.

METHODS OF MEASURING AND COMPUTING STREAM FLOW.

WEIRS.

The discharge of a stream can be obtained by causing it to flow over a weir or dam the coefficient of which is known, by the substitution of observed data in a weir formula. Three sharp-crested or standard weir formulæ are in use, viz, Francis's, Fteley and Stearns's, and Bazin's. They differ much in form, and each is derived from experiments on small weirs with low heads. A brief discussion of

each formula is here given because of its bearing on the accuracy of discharge measurements. Bazin has determined the values of the coefficient of discharge over weirs of many other shapes of crest, and the Cornell University experiments of the Board of Engineers on Deep Waterways have extended the values of the coefficients of a few of these to the higher heads. Time and space, however, will not permit more than the mention of them here.[a]

The weir is the most accurate method of measuring discharge yet used for small streams if the coefficient of the weir be accurately known. The head on the weir and the velocity of approach are the only variables, and these can easily and accurately be measured. The disadvantages are (1) the cost of constructing a weir, or the difficulty of finding one in use whose shape closely resembles one whose coefficient is known, and (2) the limited range of values of the coefficient of a weir of any shape and the limited number of shapes that have been investigated.

FRANCIS'S EXPERIMENTS AND FORMULA.

In 1852 J. B. Francis made numerous very careful measurements of the volume of water passing over small weirs and the corresponding heads at Lowell, Mass.[b] His measuring tank was a canal lock which had a capacity of 12,138 cubic feet for a depth of 9.5 feet; the greatest length of crest was 10 feet; the head on the weir varied from 5 to 19 inches, and was measured with two hook gages 6 feet upstream from the crest; the width of the channel was about 14 feet. His formula, derived from these experiments, is as follows:

$$Q=\tfrac{2}{3}\times 0.622\ h_2(b-\tfrac{1}{10}\ nh_2)\sqrt{2\ gh_2}=3.33(b-\tfrac{1}{10}\ nh_2)h_2^{\frac{3}{2}}$$

Q=discharge in cubic feet per second; h=head on weir, or difference in elevation of weir crest and water surface; n is a constant whose value is 0 when both ends of the weir are flush with the sides of the channel, 1 when one side only is flush, and 2 when neither side is flush; g=acceleration of gravity. (See fig. 9.) The head on the weir should be not less than 0.5 foot nor more than 2 feet, the depth of water in the canal should be at least three times the head on the weir, and the air should have free entrance under the sheet. The velocity of approach of the water to the weir must be

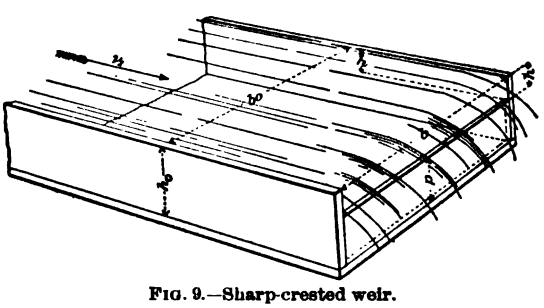

FIG. 9.—Sharp-crested weir.

[a] A discussion of these experiments, which were conducted by George W. Rafter, will be found in Trans. Am. Soc. Civ. Eng., Vol. XLIV, pp. 220-398.

[b] Lowell Hydraulic Experiments, by J. B. Francis, p. 133.

measured and the head corrected for it. The formula for this purpose is $h_2=[(h+h_1)^{\frac{3}{2}}-h_1^{\frac{3}{2}}]^{\frac{2}{3}}$, h being the measured head, h_1 the head due to the velocity of approach $=\frac{V_1^2}{2g}$ and $V_1=\frac{Q}{b_0h_0}$. (See fig. 9.)

Hamilton Smith, jr., says of this formula:[a] "It stands in the first rank in reliability."

Francis made eighty-eight experiments with two weirs of 10 and 8 feet length, in addition to those to derive his formula, and found that the greatest percentage difference between his measured discharge and the discharge computed by his formula was 0.9 per cent for the mean of two experiments and 0.68 per cent for the mean of eight experiments; for the other eleven means the difference is less than 0.4 per cent.

FTELEY AND STEARNS'S EXPERIMENTS AND FORMULA.

In 1877 and 1879 Fteley and Stearns[b] measured the discharge over weirs of 5 and 19 feet crest length and the corresponding head on weir, from which they derived the following formula for a standard weir with end contractions suppressed:

$$Q=3.31b\left[h+1.5\frac{V_1^2}{2g}\right]^{\frac{3}{2}}-0.007b.$$

Q=discharge in cubic feet per second, b=length of crest, h=head on weir, V_1=velocity of approach in feet per second. (See fig. 9.) Their measuring tank was a section of the Sudbury conduit having a capacity of 300,000 cubic feet for an increase in depth of 3 feet. The head on the weir was measured with a hook gage 6 feet upstream from the crest. The term $1.5\frac{V_1^2}{2g}$ corrects for velocity of approach. The head on the weir must be not less than 0.06 foot, and the air must have free access under the sheet. This formula is not used as generally as is that of Francis or Bazin. It was used by Fteley and Stearns to compute the discharge of the weir used in their current-meter and weir comparisons. (See p. 57.)

BAZIN'S FORMULA.

In 1886 and 1887 Bazin[c] made numerous measurements of the volume passing over weirs having lengths of from 0.5 meter to 2 meters and the corresponding heads. From these he derived the following formula for a standard weir with end contractions suppressed:

$$Q=\tfrac{2}{3}\mu\left[1+0.55\left(\frac{h}{p+h}\right)^2\right]bh\sqrt{2gh}$$

$$\text{and } \mu=0.6075+\frac{0.0148}{h\text{ (in feet)}}.$$

[a] Hydraulics, by Hamilton Smith, p. 93.
[b] Trans. Am. Soc. Civ. Eng., Vol. XII, p. 1.
[c] Annales des ponts et chaussées, 1888, p. 416.

This formula is true for any system of units (feet or meters). Q=discharge, b=length of crest, h=head on weir, p=distance of crest above bottom. (See fig. 9.) This formula needs no correction for velocity of approach. The measuring tank was a section of a rectangular channel 200 meters long, 2 meters wide, and 1.2 meters deep. The head on the weir varied from 0.05 meter to 0.6 meter. The air had free access under the sheet. Each of these formulæ will give the discharge to within about 1 per cent if the conditions existing when the observations on which the formula is based are exactly duplicated. Discharges computed from any two of these formulæ may differ 3 per cent.

CURRENT METERS.

If the stream be small, meter measurements are made from a bridge, if one can be found in a suitable location. Bridge piers, however,

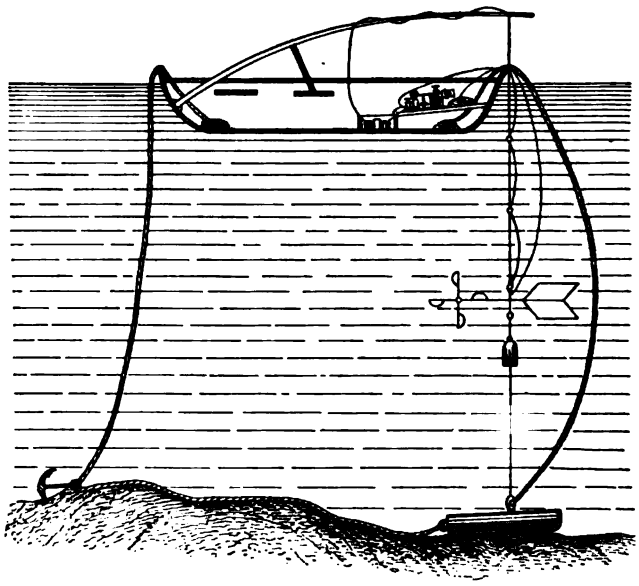

FIG. 10.—Method of using current meter on large river.

disturb the natural flow of a stream, as well as distort the vertical and transverse velocity curves and render them of only local application. Discharge measurements made where there are piers in the channel are, as a rule, less accurate than measurements made where there are no piers to obstruct the flow.

In case there is not a bridge at the desired place, the observer wades, if the water be shallow, taking observations of depth and velocity at as many points in the cross section as desired. If the water be deep and swift a cable is stretched across the stream at a convenient height above the water, and a car or box is suspended from it. From

this car, which is moved back and forth across the stream by the observer in it, the depth and velocity of the water are measured. If the current be not swift a surveyor's chain or a cable can be stretched across the stream temporarily and the depth and velocity be measured from a rowboat at points marked on the chain or cable.

In a large river like the Mississippi, where a steamboat can conven-

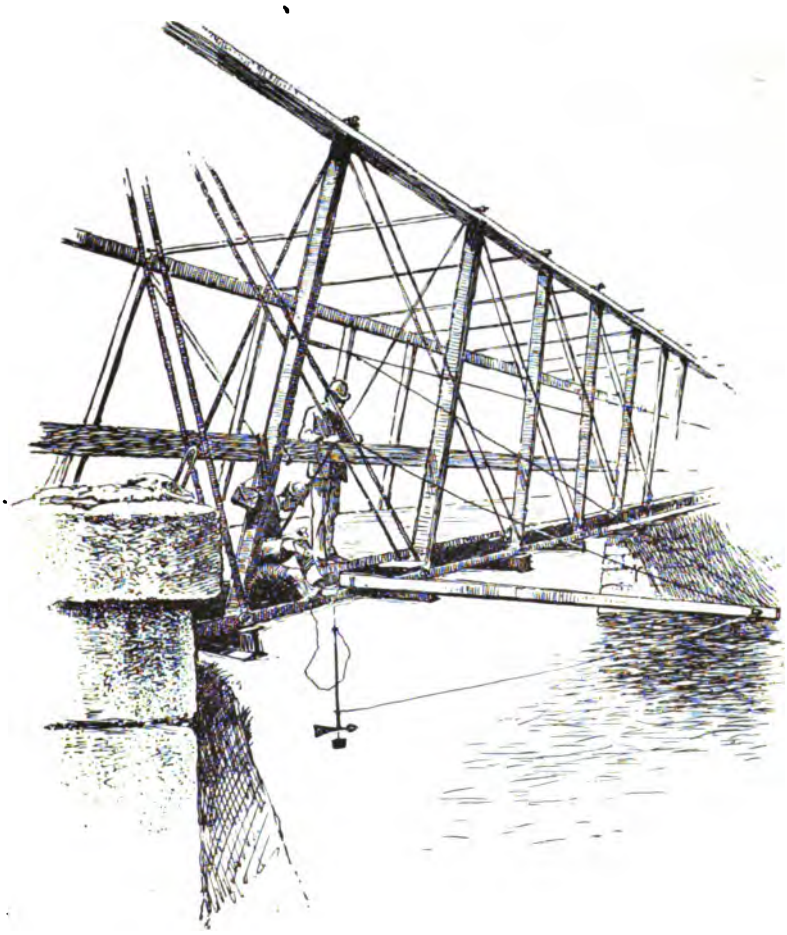

FIG. 11.—Device for holding meter in place.

iently anchor, a method that has been used satisfactorily is shown in fig. 10.[a] The boat is anchored in the proper place, and a lead weight of 50 pounds connected to the anchor is lowered over the stern. A copper wire is connected to this weight and to the spring pole in the boat, and the meter is moved up and down on this wire by a rope. The revolutions of the meter are recorded electrically in the boat, the cop-

[a] Jour. Franklin Inst., Vol. LXII, p. 171.

per wire being connected to one pole of the battery and an insulated wire connected to the meter and the other pole.

On large rivers where boats can not anchor the measurements are made from a boat towed by a steamboat.[a] The meter is kept in position by two lines of range poles at right angles to each other. The pilot on the steamboat steers it so as to keep it in line with one range, while the engineer, with his hand on the steam valve and his eye on the other range, controls the speed of the boat so that it will remain in a fixed position.

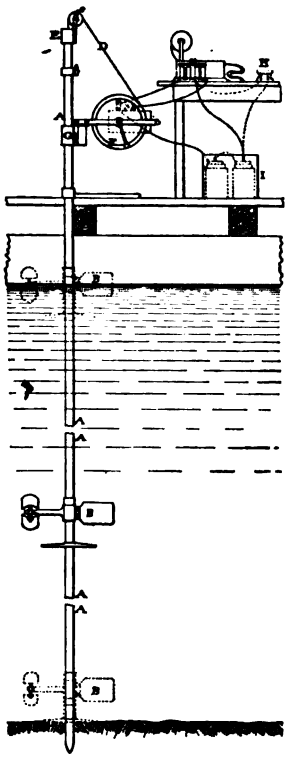

FIG. 12.—Harlacher's apparatus for moving a meter with uniform velocity.

In a swift current the meter and its sinker will be carried downstream a distance depending on the weight of the sinker and the depth and velocity of the water. There are two methods of treating this difficulty. One is to apply a special device like that shown in fig. 11 to keep the meter in place;[b] the other is to compute from the weight of the sinker and the depth and approximate velocity of the water the additional length of cable to use in order that the meter may sink to the required depth.[c] The first is the better for streams of ordinary size. In the device shown in fig. 11 the stay line is attached to the meter and is passed over a pulley at the end of the stay pole, being held by an assistant. By means of this stay line and the vertical cord the meter can be kept nearly in position. Instead of a stay pole a wire cable is sometimes used to keep the stay line in place.

POINT AND INTEGRATION METHODS.

There are two methods of using a meter in a cross section, as follows: (1) The point method, in which the meter is held at certain points in the cross section for a stated period of time, usually fifty seconds, and the number of revolutions of the wheel of the meter during that time are observed, either by counting the clicks of a buzzer or reading a register; and (2) the integration method, in which, instead of holding the meter at certain points, it is moved with a uniform speed through the section, the time and number of revolutions being observed as before. The point method is the more accurate if sufficient observations are taken in the section. The velocity found by the integration method is the resultant of

[a] Jour. West. Soc. Eng., Vol. III, No. 3.
[b] Twentieth Ann. Rept. U. S. Geol. Survey, Pt. IV, p. 20.
[c] Jour. West. Soc. Eng., Vol. IV, No. 6.

the velocity of the water and that of the meter as it is carried by the observer, and must always be greater than the true velocity. The error increases with the speed of the meter, and also increases as the velocity of the water decreases. When the point method is used the meter may be held at several points in certain verticals, in which case we will call it the ordinary method; or it may be held

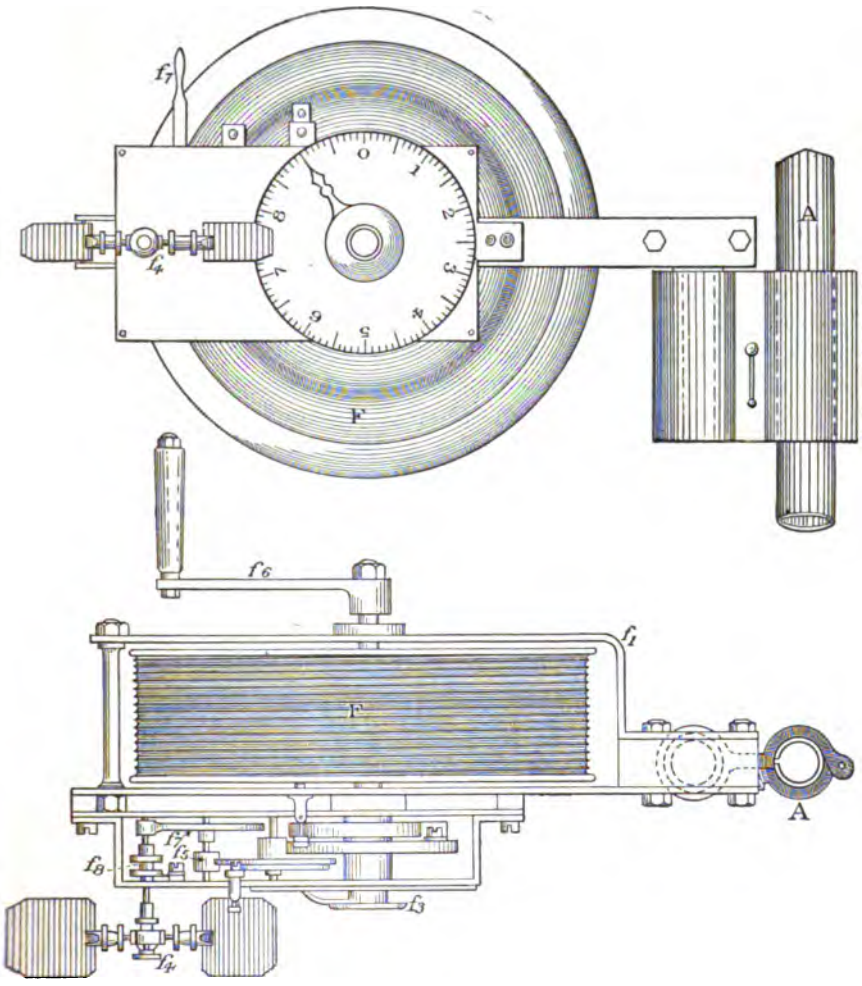

FIG. 13.—Details of Harlacher's apparatus for moving a meter with uniform velocity.

at the surface, at mid depth, and at the bottom in certain verticals, and the discharge be found from these (see Moore's method, p. 45); or it may be held at the surface and the bottom only in several verticals, and the mean velocity be found from these; or it may be held at three-tenths, at six-tenths, or at mid depth in certain verticals, and the mean velocity be found by applying a factor. The

three-tenths-depth point[a] is used because it is said to be the point of maximum velocity in a vertical, and a small error in the position of this point will not affect the result much. The mid-depth point[b] is employed because the factor which is used to obtain the mean velocity is more nearly constant for it than for any other point on a vertical curve. The six-tenths-depth point[c] is used because it is believed to be the depth of the thread of mean velocity.

In the integration method the meter may be moved down several times in certain verticals only, as used by Harlacher,[d] or across the stream at a given depth, as used by Price on the Mississippi River at Carrollton, La.,[e] or diagonally across from one side to the other at the same time that it is moved from the surface to the bottom several times, as used by the writer and others. Harlacher's apparatus for moving a meter with a uniform velocity is shown in figs. 12 and 13. The meter B is moved up or down on the iron tube AA by the rope D attached to the drum F. E is a bracket holding the pulley e. G is an arm supporting the drum F, and f_3 (fig. 13) is a dial on which is registered the depth. The fan f_4 (fig. 13) and the gearing f_5 regulate the rate of motion of the meter; f_6 is a crank lever for raising the meter, and f_8 a ratchet wheel for arresting the motion. I (fig. 12) is an electric battery, and H (fig. 12) is the registering apparatus.

When accurate results are desired the meter should be held with a rod, if the depth be not too great, in which case it is not free to turn sidewise, but keeps its axis parallel to the axis of the stream and can be placed close to the bottom. Ordinarily it is held with an insulated wire, and is free to take the direction of the water at the point where it is held.

COEFFICIENT WORK.

Coefficient work in river gaging consists of obtaining the ratio of the velocity at any point in the depth of the stream (called the index point), as, for example, the three-tenths-depth point, to the mean velocity in the whole depth. When this ratio or coefficient is known for a vertical, the mean velocity in that vertical can be found by making an observation at the index point and applying the coefficient.

Let C_1, C_2, C_3, etc., be the coefficients for the component parts, F_1, F_2, F_3, etc., of the discharge area F; V_1, V_2, V_3, etc., the observed velocities at the index points of these areas; and V the mean velocity for the whole discharge area. The discharge $Q = FV = C_1F_1V_1 + C_2F_2V_2 + C_3F_3V_3 + \ldots\ldots$ (1).

A value of each of these coefficients can be found for each foot variation of river stage. The discharge of the stream is then computed by equation (1) from observed values of V_1, V_2, V_3, etc., at the

[a] Jour. West. Soc. Eng., Vol. III, No. 3.
[b] Report on Current Meter Observations, Burlington, Iowa, by Maj. A. McKenzie, 1884.
[c] Proc. Inst. Civ. Eng., Vol. LXXI, p. 60.
[d] Ibid., Vol. LXVII, p. 358.
[e] Jour. West. Soc. Eng., Vol. III, No. 3.

index points, using the set of values of the coefficients which correspond with the observed river stage.

Coefficient work can be done with one current meter, but it can be done more rapidly with two or more meters. When two meters are used, one is placed at the index point and the other is held for several minutes at as many points in the vertical as desired, and simultaneous readings of the two meters are obtained at each point. The two meters are occasionally held at the same depth and relative readings of the meters are obtained. A chart can be prepared from the ratings of the meters in still water which will give the velocity ratio from the simultaneous readings of the two meters. For example: The index meter at three-tenths depth indicates 2.34 revolutions per second. The other meter, at eight-tenths depth, indicates 2.05 revolutions per second. The chart shows the velocity ratio for these meter speeds to be 0.89. From the velocity ratio at each tenth of the depth the ratio of the mean velocity in the vertical to the index velocity, or C, is found.

This coefficient method of gaging is better and more accurate for large streams than the slower one in which velocity observations are made at several points in each vertical, on account of the rapid changes of surface elevation of the stream.

RATING OF METERS AND CONSTRUCTION OF RATING TABLES.

The accuracy of a discharge measurement depends largely on the accuracy of rating the meter used. Errors of observation are as likely to be too large as too small, and are compensating. Errors in a rating table always have the same sign and are cumulative, hence they should be eliminated or reduced to a minimum.

There are two kinds of rating of a current meter, absolute and relative. From the former the absolute velocity at a single point is found; from the latter the ratio or coefficient of velocity at any two points is found. The former is usually employed in still water, the latter in running water.

Four methods have been used for rating meters: (1) By the use of surface floats; (2) by moving the meter through still water with a known velocity; (3) by observing velocity at many points in a cross section and comparing this with the known mean velocity; and (4) by attaching the instrument to a long arm and revolving it about a vertical axis in a body of still water. The second method is the one now universally used. The meter is suspended from a car or a boat and is moved with a uniform velocity through still water at a depth of 2 or more feet below the surface. The length of a run varies from 100 to 300 feet, with a starting run sufficient to allow the meter wheel to reach the proper speed before entering the run. It is moved across and back over the run to eliminate the effect of velocity in either direction. The rating equipment should be such as to give time of

run to the tenth of a second and speed of meter to the tenth of a revolution (a chronograph recording time, revolutions, and the instants of beginning and ending the run should meet this requirement).

The range of velocities employed in rating should be those for which the meter is to be used. If it is to be employed mainly to measure low velocities the speeds in rating should be low. The rating table should not be extended beyond the limits of velocity used in the rating.

The relation between distance passed over by the meter and the corresponding revolutions of the meter wheel is often assumed to be a straight line. It is always a curved line, and must be so on account of friction of bearings and inertia of moving wheel. A velocity of from 0.1 to 0.5 foot per second is necessary to start the wheel. As the velocity increases the effect of friction and inertia becomes proportionately less and the curve approaches a straight line. The relation between velocity and revolutions of wheel per second is of the second degree and concave to the axis of velocity. For velocities of 2 or more feet per second this curve differs little from a straight line.

The results of the rating are usually plotted on squared paper, using revolutions per second as ordinates and velocity as abscissæ, and all observations that fall much from a well-defined line are rejected. If this line be nearly straight between the limits of the observed revolutions its equation is assumed to be of the form $y=a+bx$, y being velocity, x revolutions per second, and a and b constants. If the results indicate a curved line its equation is assumed to be of the form $y=a+bx+cx^2$. There are two methods of preparing the rating table from the observations. The first method is rapid. The most probable curve is drawn among the plotted observations, and the velocities to tenths of a revolution are read from the curve. In the second method the equation of the most probable relation is derived by the method of "least squares" and then the table is prepared from the equation. The writer has found it better to plot values of x and the ratio y to x (see fig. 29, p. 89) instead of x and y. The reason is that the ratio y to x changes rapidly as x increases and can be read more accurately from this curve than from a nearly straight line. It can be shown mathematically that these curves are approximately branches of hyperbolas.

The second method, which is to derive the equation of the most probable relation between velocity and revolutions by the method of "least squares," first rejecting the observations that fall much outside of a well-defined curve, is the most accurate, but it requires the most time. If the meter is to measure low velocities to within 1 per cent, the second method must be used. It gives n observation equations of the form $y-a+bx=v$ if the relation be linear, or $y-a-bx-cx^2=v$ if it be a parabolic curve. v is a small quantity called a residual, or a residual error. Its value would be zero if the observations were perfect. According to the principle of least squares, the best values

of the constants are those that make the sum of the squares of the residuals a minimum.

Squaring each of these n equations and adding, we have

$$\Sigma v^2 = v_1^2 + v_2^2 + v_3^2 + \ldots = [y' - a - bx' - cx'^2]^2 + [y'' - a - bx'' - cx''^2]^2 + [y''' - a - bx''' + cx'''^2]^2 + \ldots$$

Taking the first derivative of this equation with respect to a, b, and c and placing these equal to 0, we have

$$d\frac{(\Sigma v^2)}{da} = -2\,[y' - a - bx' - cx'^2] - 2\,[y'' - a - bx'' - cx''^2] \ldots = 0$$

$$d\frac{\Sigma v^2}{db} = -2x'\,[y' - a - bx' - cx'^2] - 2x''\,[y'' - a - bx'' - cx''^2] \ldots = 0$$

$$d\frac{\Sigma v^2}{dc} = -2x'^2\,[y' - a - bx' - cx'^2] - 2x''^2\,[y'' - a - bx'' - cx''^2] \ldots = 0$$

From these normal equations the values of a, b, and c can be found.

For the linear function these equations become two in number and have the form

$$a\Sigma x + b\Sigma x^2 = \Sigma xy$$
$$na + b\Sigma x = \Sigma y$$

and a and b are found from these equations.

This relation between revolutions per second and velocity, whatever it may be, is not constant. Below are given the ratings of a Price meter, obtained by J. C. Bailey, United States assistant engineer.[a]

Results of four ratings of a Price meter used in 1892 on Niagara River.

Date.	Number of observations.	Velocity.	Meter coefficients.		Remarks.
			a	b	
		Ft. per sec.			
April 28	20	2.5 to 7.8	4.239	+0	Still water; base 150 feet long.
April 29	34	2.1 to 6.7	4.256	+0.061	Do.
May 4	49	1.7 to 7.7	4.046	+0.207	Do.
May 17	43	2.0 to 8.0	4.130	+0.067	Still water; base 300 feet long.
			4.168	+0.0848	

Values computed from two ratings of current meter on April 29 and May 4, 1892.

[April 29, $V_1 = 4.256\,R + 0.061$; May 4, $V_2 = 4.046\,R + 0.207$.]

R	V_1	V_2	$V_2 - V_1$	$\frac{V_2 - V_1}{V_2}$
0.05	0.274	0.409	0.135	0.314
0.10	0.487	0.612	0.125	0.204
0.15	0.699	0.814	0.115	0.141
0.20	0.912	1.016	0.104	0.102
0.25	1.125	1.219	0.094	0.077
0.30	1.338	1.421	0.083	0.058
0.35	1.551	1.623	0.072	0.044
0.40	1.763	1.825	0.062	0.034
0.45	1.967	2.028	0.052	0.026
0.50	2.189	2.230	0.041	0.018

[a] Engineering News, Vol. XXIX, 1893.

The foregoing table shows that if on May 4 velocity measurements had been made from 0.05 to 0.50 revolution per second and the rating table of April 29 had been used the results would be in error from 1.8 per cent to 31.4 per cent. It is true that neither set of values of a and b was determined for low velocities. This, however, emphasizes the fact that values of a and b found for high velocities may be greatly in error for the low velocities if the linear relation is assumed. These four ratings of a meter in less than one month show considerable variation in the values of a and b, and indicate that when a meter is in constant use its rating should be examined once a week if accurate work is required.

A rating table that gives velocity to only two places of decimals is not sufficiently accurate for low velocities. To illustrate this we will take the case of the rating table of small Price meter No. 363, rated at Chevy Chase, Md., June 26, 1900. The velocity corresponding with 0.05 revolution per second is given as 0.17 foot per second. This may mean any value from 0.166 foot per second to 0.174 foot per second. This is 2.04 per cent of 0.17. Hence if the computed revolutions were either 0.166 or 0.174 the error introduced by using this rating table would be 2.4 per cent. The following table shows the error for other velocities given in this rating table. If the velocity be 0.25 foot per second it may be in error nearly 2 per cent if found from this table.

Table showing greatest percentage error in rating table of small Price meter No. 363, which gives velocity to only two places of decimals.

Revolutions per second.	Velocity.	Error $\frac{0.004}{V}$.	Revolutions per second.	Velocity.	Error $\frac{0.004}{V}$.
	Ft. per sec.	*Per cent.*		*Ft. per sec.*	*Per cent.*
0	0.06	6.7	0.25	0.63	0.6
0.05	0.17	2.4	0.30	0.75	0.5
0.10	0.29	1.4	0.35	0.86	0.5
0.15	0.40	1.0	0.40	0.98	0.4
0.20	0.52	0.8	0.45	1.09	0.4

Darcy and Bazin employed the first three methods to rate the Pitot tube which they used in their hydraulic investigations on canals.[a] Fig. 2, page 19, shows this instrument as they used it. A discussion of the results of the ratings is given here on account of the light they throw on accuracy tests.

[a] Recherches hydrauliques, by Darcy and Bazin, 1865, pp. 63-70.

Results of Pitot tube ratings by Darcy and Bazin.

First method.[a]			Second method.[b]			Third method.[c]					
No. of experiment.	Value of coefficient.	Number of experiments.	Velocity of boat.	Value of coefficient.	Number of experiments.	Designation of experiment.		Value of coefficient.	Mean Velocity.	Channel.	
						Series.	No.			Shape.	Width.
			Meters.						*Meters.*		*Meters.*
2	0.987	8	0.609	1.040	2	51	1	1.021	0.508	(d)	0.8
3	1.024	8	0.692	1.053	1	51	2	1.010	0.768	(d)	0.8
4	0.981	8	0.785	1.032	3	51	3	1.018	1.028	(d)	0.8
5	1.013	8	0.938	1.033	1	52	1	1.029	0.376	(d)	0.48
6	1.006	8	0.980	1.040	3	52	2	1.000	0.542	(d)	0.48
7	0.988	8	1.120	1.015	1	52	3	1.006	0.694	(d)	0.48
8	1.012	8	1.251	1.028	1	58	4	1.005	1.429	(d)	1.994
9	1.008	4	1.333	1.032	1	59	4	0.969	2.318	(d)	1.994
10	1.008	4	1.385	1.048	1	60	2	0.968	2.571	(d)	1.994
11	1.009	4	1.470	1.029	1	61	4	0.966	1.267	(e)	1.994
12	1.007	4	1.500	1.040	1	62	4	0.965	1.979	(e)	1.994
13	1.015	4	1.611	1.033	2	63	3	0.988	2.199	(e)	1.994
14	1.039	4	1.661	1.027	1	64	1	0.996	0.856	(e)	1.994
15	0.994	4	1.775	1.042	1	64	2	0.988	0.948	(e)	1.994
16	1.007	4	1.819	1.031	3	65	4	0.978	1.511	(e)	1.994
17	1.023	4	1.863	1.027	3	66	1	1.015	1.464	(e)	1.994
.....	.....	.....	1.930	1.039	1	66	2	0.984	1.675	(e)	1.994
.....	.....	.....	1.976	1.025	4	68	4	0.976	1.497	(f)	1.984
.....	.....	.....	2.034	1.037	1	71	6	0.968	1.810	(g)	1.40
.....	.....	.....	.....	.....	.....	72	5	1.017	1.679	(g)	1.40
.....	.....	.....	.....	.....	.....	73	4	0.967	1.612	(g)	1.40
.....	.....	.....	.....	.....	.....	74	4	1.014	1.229	(g)	1.40
.....	.....	.....	.....	.....	.....	84	2	1.014	1.033	(h)	1.990
.....	.....	.....	.....	.....	.....	84	3	0.984	1.246	(h)	1.990
.....	.....	.....	.....	.....	.....	85	1	0.998	1.011	(h)	1.990
.....	.....	.....	.....	.....	.....	85	2	0.997	1.218	(h)	1.990
.....	.....	.....	.....	.....	.....	85	3	0.990	1.473	(h)	1.990
.....	.....	.....	.....	.....	.....	88	1	0.995	0.894	(h)	1.990
.....	.....	.....	.....	.....	.....	88	2	0.986	0.921	(h)	1.990
.....	.....	.....	.....	.....	.....	88	3	0.980	0.955	(h)	1.990
.....	.....	.....	.....	.....	.....	88	4	0.993	1.010	(h)	1.990
	1.006			1.034				0.993			

[a] By surface floats.
[b] In still water.
[c] In moving water.
[d] Rectangular covered wooden channel.
[e] Rectangular open wooden channel covered with cloth.
[f] Trapezoidal open wooden channel covered with cloth.
[g] Semicircular.
[h] Rectangular.

In the first method the floats were run over a distance of 40 meters and the tube was held with its point 0.02 meter below the surface of the water. C is found from $v=C\sqrt{2g\frac{\Sigma d}{2}}$, v being known from the floats. In the second method the tube was fastened in front of a boat and was drawn through still water at different observed velocities. In the third method the instrument was held at many points in a cross section of an experiment canal 2 meters wide, the mean velocity in which was known, and the mean velocity as shown by the tube was computed.

It is seen that the three values of C found by these three methods differ somewhat, although each is the mean of many observations. The value found by the second method (the one now commonly used) is the largest of the three and is rejected on account of the action of the boat on the instrument. The pull on the boat as it was drawn through the water tipped the point of the tube down slightly, making

its indications less than they should be and making C too large. By the first method the mean of experiments Nos. 2 to 8 is 1.0016 and the mean of experiments Nos. 9 to 17 is 1.0122. The difference between these is nearly 1 per cent of the former. The greatest variations from the mean of all the observations by the first method are +1.8 per cent and −2.5 per cent. The value of C found by the third method is 0.993, obtained from thirty-one measurements of discharge of the experiment canal. The tube was held at many points in the cross section. The variations from this mean are +3.6 per cent and −2.8 per cent. Darcy uses the mean of the values found by the first and third methods, which makes $C=1$. The extreme variations from this mean are +3.9 per cent and −3.5 per cent. The velocity of the water during these ratings varied from 0.5 to 2.5 meters per second, or from 1.64 feet to 8.20 feet per second.

GENERAL FORMULÆ FOR COMPUTING DISCHARGE.

Whatever method is used in computing discharge, the depth must be known at a sufficient number of points in the cross section to determine the cross-sectional area with the required degree of accuracy. For a small stream it should be known at each foot of width, for large streams at each 5 or 10 feet of width.

The cross-sectional area (F) is found from the following formula:

$$F=\frac{b}{-}\left[d_1+4\left(d_2+d_4+d_6+d_{n-1}\right)+2(d_3+d_5+d_7+dn)+dn+1\right]$$

d_1, d_2, d_3, etc., being depths and b the distance between the points where the depths are measured.

The general formula for the discharge per second is

$$Q=F_1V_1+F_2V_2+F_3V_3+F_nV_n. \qquad (1)$$

F_1, F_2, F_3, etc., are the component parts of the cross section, and V_1, V_2, V_3, etc., the mean velocity in each of these parts. If the width of these component parts is b and the mean depth in each is d_1, d_2, d_3, this formula can be written

$$Q=b\left(V_1d_1+V_2d_2+V_3d_3+\text{——}\right). \qquad (2)$$

If $d_1=d_2=d_3$—, that is, if the channel is rectangular in cross section, then formula (2) becomes

$$Q=bd\left(V_1+V_2+V_3+\text{——}\right). \qquad (3)$$

The component velocities are found (1) from a single observation at some depth by applying a coefficient, as a mid-depth velocity observation multiplied by 0.95, or a six-tenths-depth observation multiplied by unity, and (2) from a vertical velocity curve. The latter, as already explained, is found from numerous observations at points in the depth, and the mean velocity in this vertical is then the area inclosed between the vertical curve and a vertical line representing no

velocity divided by the depth. Harlacher's method of integrating[a] in a vertical gives each component velocity very readily and quickly. Any component velocity is $\frac{RC}{T}$, R being the observed revolutions, T the observed time in seconds, and C the number, which changes from revolutions to velocity.

In measuring the discharge of a large river the component velocities are always found from an observation at some given depth and the use of a coefficient. As the depth or stage of a river is almost constantly changing, it is necessary to make the velocity observation in a short time—one or two hours at most. The value of the coefficient to use to reduce observed velocity at any depth to mean velocity in that vertical should be found from measurement if possible.

The discharge measurements of the Niagara River made in 1897 and 1898 by the United States Board of Engineers on Deep Waterways[b] from the international bridge 3 miles below the head of the river, were computed from velocity observations at three-tenths depth, using coefficients whose values were found from vertical velocity curves. The meter stations were about 80 feet apart and were at the middle of each half span of the short spans and at the middle of each one-third span of the long spans. The value of the coefficient for reducing observed velocity to mean velocity ranged from 0.61 to 1.17, being influenced by the piers of the bridge.

T. V. Moore in his discharge measurements of the Thames[c] assumed the vertical velocity curve to be a parabola, and computed its area from the formula $A=\frac{d}{6}[V_s+4V_m+V_b]$, d being the depth, V_s the surface velocity, V_m the velocity at mid depth, and V_b the bottom velocity. The discharge per second flowing between the end sections he computed from the formula $V=\frac{h}{3}[\Sigma A_1+4\Sigma A_2+2\Sigma A_3]$, h being the distance between the consecutive sections, ΣA_1 the sum of the two end sections, ΣA_2 the sum of the odd sections, and ΣA_3 the areas of the even sections. The discharge is found by adding to this the small volume flowing between each end section and the shore.

T. G. Ellis, in computing the discharge of the Connecticut River in 1874, multiplied the velocity at mid depth in each component area by 0.95 to find the mean velocity in that area.[d] In computing the discharge of the Mississippi River in 1882 the velocity at mid depth in each component area was multiplied by 0.91 for the observations taken when the river was covered with ice, and by 0.96 when free from ice, to reduce the mean velocity in a vertical.[e] From 1885 to 1887 the velocity at six-tenths depth was observed in the component areas, and this was taken as the mean velocity in each area.

[a] Proc. Inst. Civ. Eng., Vol. LXVII, p. 358.
[b] Jour. West. Soc. Eng., Vol. IV, No. 6.
[c] Proc. Inst. Civ. Eng., Vol. XLV, p. 220.
[d] Trans. Am. Soc. Civ. Eng., Vol. IV, p. 303.
[e] Jour. West. Soc. Eng., Vol. III, No. 3.

Harlacher's method of computing flood discharge where the surface velocity only could be measured is illustrated in fig. 14.[a] The surface velocity was measured at a sufficient number of points (1, 2, 3, etc.) in the cross section *ACB* to determine the surface velocity curve *ADB*. The line *ACB* shows the depth at each point and is plotted from soundings taken immediately before or after the flood.

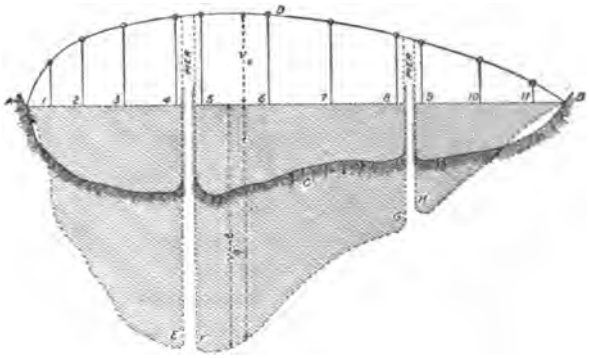

FIG. 14.—Diagram illustrating Harlacher's method of computing flood discharge.

The openings between *EF* and *GH* are bridge piers, the measurements being made from a bridge. The product of the surface velocity v_s and the corresponding depth t is found for a sufficient number of points, depending on the irregularity of the bottom and the curve *AEFGHB* drawn. The discharge per second is the area between the line *AB* and the curve *AEFGHB*, less the piers, multiplied by 0.85.

COMPARISONS OF RESULTS WITH DIFFERENT INSTRUMENTS AND METHODS.

SURFACE FLOATS AND PITOT TUBE.

On page 43 we have given the results of three ratings of a Pitot tube by Darcy and Bazin.[b] In the first method the surface velocity was found from surface floats and a Pitot tube, as already described. Ninety-two experiments were made. The results are combined, according to velocity, into seven groups of eight experiments each and nine groups of four experiments each. The value of the coefficient as found from the first seven groups differs from that found from the mean of the last groups by about 1 per cent. The extreme variations of these individual means from the mean of all the experiments are − 1.8 per cent and + 2.5 per cent. The individual values of the coefficient are not given. Their extreme variation from the mean of all must be at least twice that of the individual means from the general mean.

[a] Proc. Inst. Civ. Eng., Vol. XCI, p. 399.

[b] Recherches hydrauliques, by Darcy and Bazin, 1865, pp. 63-70.

PITOT TUBE AND RECTANGULAR ORIFICES.

On page 43 are given the results of a third rating of a Pitot tube by Darcy and Bazin (third method). This is also a comparison of the discharge of a canal 2 meters wide, as found from rectangular orifices and as found from numerous velocity measurements in a cross section of the canal with the same Pitot tube. The discharge of the rectangular orifices admitting water to the canal was determined by experiment for different heads on them. The number of velocity measurements in each experiment or discharge measurement varied with the depth of the water in the canal, being from twenty-seven in the smallest channel, which was 0.30 meter by 0.48 meter, to ninety-one in the canal 2 meters wide. The points of measurement were nearest together where the velocity changed most rapidly. The results of thirty-one discharge measurements are given, the mean velocity varying from 0.38 meter to 2.57 meters per second. The extreme variations from the mean of all the values of the coefficient are + 3.6 per cent and — 2.8 per cent.

DOUBLE FLOATS AND CURRENT METER.

ELLIS'S EXPERIMENTS.

In 1874 T. G. Ellis made numerous velocity measurements of the Connecticut River at Thompsonville, Conn., with current meters and with double floats like that shown in fig 1.[a] Vertical velocity curves were obtained in planes parallel with the axis of the river and 100 feet apart, with the meters and with the floats. Each of these curves was plotted on cross-section paper and divided into tenths of the depth. All of the curves in which the mean velocity was less than 1.86 feet were combined by combining all the observations at each tenth of depth; all in which the mean velocity was more than 1.86 feet were combined in the same way. From the resultant vertical velocity curves the results in the following table are taken:

Comparison of velocity by double floats and current meters from measurements by T. G. Ellis on Connecticut River in 1874.

Observations.	Mean velocity, in feet per second, at various depths.											Mean.	Variation.
	Surface.	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	Bottom.		
													P. ct.
Meter below av. velocity 1.86	1.15	1.19	1.22	1.22	1.19	1.14	1.11	1.03	0.94	0.79	0.46	1.063	25.8
Float below av. velocity 1.86	1.50	1.52	1.52	1.53	1.49	1.46	1.35	1.29	1.20	0.97	0.58	1.337	
Meter above av. velocity 1.86	2.96	3.08	3.12	3.06	2.99	2.91	2.78	2.62	2.42	2.16	1.47	2.735	5.7
Float above av. velocity 1.86	3.26	3.24	3.17	3.17	3 11	3.01	2.94	2.80	2.60	2.35	1.78	2.891	
All meter observations	2.05	2.12	2.15	2.13	2.08	2.01	1.93	1.81	1.67	1.47	0.96	1.887	12.0
All float observations	2.38	2.38	2.35	2.35	2.30	2.23	2.15	2.04	1.90	1.60	1.18	2.114	

[a] Rept. Chief Eng. U. S. A., 1878, Appendix B.

It is seen from the foregoing table that the velocity as found with the meter is from 6 to 26 per cent less than that found with the floats, and that the difference between the meter and float velocities increases as the velocity decreases.

Ellis gives also the following values of the ratio of mean velocity in a vertical (Vm) to mid-depth velocity in that vertical ($V_{\frac{1}{2}} D$) and the ratio of distance below the surface of mean velocity (m) to total depth (D).

Mean ratios from vertical velocity curves obtained by Ellis on Connecticut River in 1874.

Observations.	$Vm \div V_{\frac{1}{2}}D$	$m \div D$
Meter at low velocities	0.933	0.656
Floats at low velocities	0.918	0.622
Mean of low velocities	0.930	0.632
Meter at high velocities	0.959	0.628
Floats at high velocities	0.961	0.637
Mean of high velocities	0.944	0.629
Mean of meter measurements	0.937	0.638
Mean of float measurements	0.947	0.632
Mean of all measurements	0.940	0.636

From the foregoing table it is seen that $\frac{Vm}{V_{\frac{1}{2}}D}$ varies from about 0.92 to 0.96 and $\frac{m}{D}$ from 0.62 to 0.66—about the same range of values.

MARR'S EXPERIMENTS.

In October, 1879, G. A. Marr made simultaneous velocity measurements of the Mississippi River at Burlington, Iowa, with double floats like those shown in fig. 1 and with five current meters.[a] The river where measured was about 2,000 feet wide, and the path of the floats was near the center, where the depth was about 16.4 feet. Ten floats were run in succession in a period of about twenty-five minutes over a distance of 200 feet, and the time of entering and leaving each quarter of the run was recorded on a chronograph of eight pens. The five current meters were fastened to a cable held vertically 16 feet below the end of the run. One meter was at mid depth (the depth of the lower float), and the other four were arranged two above and two below it, so as to divide the depth into equal parts. One pen of the chronograph recorded the time of passage of each float, two recorded the time as shown by a chronometer, and the other five recorded the revolutions of the five meters. From a table giving the velocity of each float over each quarter of the run and the velocity shown by each of these meters during the time of passage over these distances the following table has been prepared:

[a] Report on Current Meter Observations, Burlington, Iowa, by Maj. A. McKenzie, 1884.

Comparison of velocity by double floats and current meters from measurements by G. A. Marr on Mississippi River at Burlington, Iowa, October, 1879.

Number of float.	Mean velocity found from 200-foot run.		Difference ($Vm-Vf$).	Mean velocity found from 50-foot run.		Difference ($Vm-Vf$).
	Float (Vf).	Meter (Vm).		Float (Vf).	Meter (Vm).	
	Ft. per sec.	*Ft. per sec.*	*Ft. per sec.*	*Ft. per sec.*	*Ft. per sec.*	*Ft. per sec.*
1	2.543	2.604	+0.061	2.660	2.597	−0.063
2	2.741	2.546	−0.195	2.976	2.657	−0.319
3	2.634	2.520	−0.114	2.674	2.630	−0.044
4	2.446	2.435	−0.011	2.456	2.481	+0.025
5	2.850	2.468	−0.382	2.847	2.590	−0.257
6	2.672	2.700	+0.028	2.778	2.649	−0.129
7	2.514	2.545	+0.031	2.674	2.484	−0.190
8	2.832	2.457	−0.375	2.857	2.749	−0.108
9	2.476	2.625	+0.149	2.569	2.821	+0.252
10	2.829	2.758	−0.071	3.012	2.823	−0.189
	2.654	2.566	.....	2.750	2.648	.....

In the foregoing observations the velocity of a float was not the same over each 50-foot length of the run. Each velocity given in the second column is a mean for the whole run of 200 feet, and the meter velocity in the third column is for the time of the full run. The velocity in the fifth column is for the fourth section of the run, and the corresponding number in that column is the meter velocity for the next consecutive and equal interval of time. The chief thing to be noticed is that the float velocity, whether computed from the whole run of 200 feet or from the shorter run of 50 feet, is greater than the meter velocity by about 3.5 per cent. We may note also that we have here forty mid-depth velocities in nearly the same vertical taken in about twenty-five minutes. For the ten found from the floats on the long run the variations of velocity from the mean are from −7.4 per cent to +7.8 per cent, and for the short run of 50 feet the variations are from −9.5 per cent to +10.7 per cent. For the meter long run the variations are from −7.5 per cent to +12.1 per cent, and for the short run from −6.5 per cent to +6.3 per cent.

Individual measurements of velocity by either of these methods differ much from the mean, but the means by the two methods differ little from each other. The excess of mid-depth velocity by double floats over that by meter may be due to the upper float dragging the lower one.

HENRY'S EXPERIMENTS.

D. F. Henry also gives a comparison of velocity measured with double floats like that shown in fig. 1 and current meter, made on the St. Clair River in 1869.[a] The results of the comparison are given in the following table:

[a] Jour. Franklin Inst., Vol. LXII, p. 322.

Comparison of velocity by double floats and current meter from measurements by D. F. Henry on St. Clair River in 1869.

Number of observations.	Direction and velocity of wind.	Depth of observation below surface.	Velocity of current.		
			Floats.	Meter.	Difference.
	Miles per hour.	*Feet.*	*Ft. per sec.*	*Ft. per sec.*	*Ft. per sec.*
50	3.26 up	1	3.619	3.655	−0.036
62	1.92 up	5	3.759	3.783	−0.024
56	1.27 up	10	3.703	3.674	+0.029
50	0.48 up	15	3.590	3.516	+0.074
54	0.29 down	20	3.598	3.405	+0.193
31	0.53 up	25	3.637	3.441	+0.196
37	0.80 up	30	3.546	3.279	+0.267
29	2.18 down	35	3.556	3.166	+0.390
12	4.85 down	40	3.636	3.142	+0.494
7	0.74 up	45	3.542	2.985	+0.557

It is seen that the float velocity is less than the meter velocity to a depth of about 5 feet. Below that depth the float velocity is greater than the meter velocity, the difference increasing with the depth. The discharge as found with the floats is 10 per cent greater than that found with the meter. While the action of the upper float on the lower float may not account for all the difference between the float and meter velocities, it will account for some of it. The velocity as shown by the vertical velocity curve increases from the surface to a depth of from 5 to 10 feet and then decreases to the bottom. The surface float will therefore move more slowly than the lower float for depths of from 0 to 5 or 10 feet, and hence the lower float will be retarded by the upper float to that depth. For depths greater than 10 feet the upper float will move faster than the lower float and will drag it, and the velocity shown will be too large.

Henry gives also a comparison of velocity as found with double floats and current meter in a small canal at Ogdensburg, N. Y.[a] The floats were run over a distance of 200 feet at 3 feet below the surface, the time being recorded on a chronograph. The current meter was held at the same depth at the middle of the run. The results are as follows:

Comparison of velocity by double floats and current meter from measurements made by D. F. Henry in small canal at Ogdensburg, N. Y., 3 feet below surface.

Number of observations.	Velocity.		
	Floats.	Meter.	Difference.
	Ft. per sec.	*Ft. per sec.*	*Ft. per sec.*
24	1.992	1.980	−0.012
6	1.876	1.916	+0.040
6	1.476	1.434	−0.042

[a] Ibid., p. 259.

These results indicate that although the mean of a few float observations may differ much from the corresponding meter velocity, the means for thirty or forty observations differ little. The meter gives a little smaller velocity than the floats.

Henry also gives a comparison of velocity found with floats and a propeller meter in the St. Clair River. The lower float was 1 foot below the surface, and the meter was held at the same depth. The mean velocity given by fifty floats was 3.619 feet per second; that by meter was 3.655 feet per second, or 0.036 foot per second greater than by floats. There was a light wind blowing upstream, and that may have retarded the floats somewhat.

GORDON'S EXPERIMENTS.

In 1873 Gordon made comparisons of the discharge of the Irawadi River at Saiktha, Burma, as measured with double floats and with current meter. From these he concluded that the double-float discharge was about 10 per cent too large. He therefore reduced all discharges found with double floats by that amount.

FLOAT RODS AND CURRENT METER.

NEW YORK STATE CANAL SURVEY EXPERIMENTS.

During the progress of the New York State canal survey of 1900 comparative discharge measurements were made on four occasions for the purpose of comparing the discharge of the canal as found by one rod-measuring party with that found by another party using similar rods and methods, and of comparing the discharge found with rods with that found simultaneously with a current meter. The results of the comparisons are summarized in the following table:

Comparison of results of experiments of New York State canal survey during the summer of 1900.

Place.	Date.	$V'r$	$V''r$	Vm	$Q'r$	$Q''r$	Qm	$Q'r-Q''r \div Q'r$	$Q'r-Qm \div Q'r$	$Q''r-Qm \div Q''r$
	1900.	*Ft. per sec.*	*Ft. per sec.*	*Ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Per ct.*	*Per ct.*	*Per ct.*
Lockport	Sept. 14		1.440	1.531		805.70	799.85			+0.73
Rochester	Sept. 20		0.704	0.736		235.12	251.57			−7.00
Do	Sept. 21	0.893	0.884		297.82	302.04		−1.41		
Do	do		0.889	0.929		301.35	310.83			−3.14
Do	do		0.899	0.939		307.08	317.54			−3.43
Boonville	Sept. 25	1.073	0.813		227.22	227.51		−0.13		
Do	do		0.850	1.079		238.81	228.66			+4.25
Do	do		0.836	1.111		233.54	234.70			−0.49
Glens Falls	Oct. 8	0.821	0.690		164.73	172.77	161.50	−4.88	+1.94	+6.52
Do	do	0.756	0.640		149.66	158.57	155.23	−5.92	−3.72	+2.11

$V'r$=mean velocity found by party No. 1, with rods.
$V''r$=mean velocity found by party No. 2, with rods.
Vm=mean velocity found with meter, using six-tenths-depth method.
$Q'r$=discharge found by party No. 1, with rods.
$Q''r$=discharge found by party No. 2, with rods.
Qm=discharge found with meter, using six-tenths-depth method.

The Lockport experiments were made on the Erie Canal about 1 mile above the locks at Lockport, in a rock cut with rough, nearly vertical sides. The meter measurements were made 700 feet above the place where the discharge was measured with rods. The observations extended over a period of thirty-four minutes, during which time 60 rods were passed over a run of 21 feet, with an immersion of 80 to 90 per cent of the depth, and 13 meter observations of 50 seconds each were made at six-tenths depth below the surface. There was no measurable fluctuation of surface level during the test.

The Rochester experiments were made on the Rochester Aqueduct, which has smooth and nearly vertical sides. The width was 43 feet and the depth 7.5 feet. The flow was undisturbed for a half mile above the section of measurement, but there was a sharp curve less than 100 feet below the point where the lower rod-measuring party was stationed. In the first comparison of rods with meter, September 20, the period of observation was forty-two minutes; 64 rods were passed over a 20-foot run with 92 per cent depth of immersion; 19 meter observations of fifty seconds each were made by the six-tenths-depth method; the surface level fluctuated 0.05 foot during the observations, and rain interfered somewhat with the work. In the first rod comparison, September 21, the observations extended over a period of sixty-five minutes; 79 rods were passed by party No. 1, with a depth of immersion of from 90 to 97 per cent, and 100 rods by party No. 2, with a depth of immersion of 92 per cent. In the first rod-and-meter comparison of September 21 the period of observation was forty-two minutes; 92 rods were passed by party No. 2, with 90 per cent depth of immersion, and 36 meter observations of fifty seconds each were taken by the six-tenths-depth method. In the second rod-and-meter comparison the period of observation was forty minutes; 80 rods were passed, with 92 per cent depth of immersion, and 36 meter observations of fifty seconds each were made at six-tenths depth.

The Boonville comparisons were made on the Black River Canal at Boonville, where the top width of the canal is 43 feet, with gradual sloping sides, and a maximum depth at center of 7.7 feet. There was an unobstructed flow for at least one-fourth mile above and a half mile below the place selected. The parties were stationed about 200 feet apart. There was practically no water entering or leaving the canal between these points. In the rod comparison, which lasted one hundred and forty-four minutes, with some interruptions, 185 rods were passed over a 20-foot run by party No. 1, and 143 rods by party No. 2. In the first meter comparison, which lasted fifty-eight minutes, 55 rods were passed and 36 meter observations were made at six-tenths depth. In the second meter comparison, which lasted fifty-three minutes, 77 rods were passed and 42 meter observations of fifty seconds each were made by the six-tenths-depth method.

The Glens Falls comparisons were made on the Glens Falls feeder, near Glens Falls. At the place selected for the tests the feeder is 32

feet wide and 6 feet deep, with nearly vertical sides. There is a bend in the feeder about 100 feet above the upper place of measurement, and another about 1,000 feet below the lower place of measurement. The meter measurements were made from a bridge about 100 feet from each of the points where the rod measurements were made. The first comparison lasted seventy-six minutes, during which time party No. 1 passed 56 rods, party No. 2 passed 90 rods, and 28 meter observations of fifty seconds each were made. In the second comparison, which lasted fifty-eight minutes, party No. 1 passed 63 rods, party No. 2 ran 108 rods, and 28 meter observations of fifty seconds each were made.

The method of making these comparisons is the same as that used in the canal discharge measurements, which is described on page 16.

The Rochester and Glens Falls comparisons are not so satisfactory as those at Lockport and Boonville. In the former the measurements were made too near a curve. The large variation in the time of run of the individual rods indicates this fact, and surface-level fluctuations and passing boats interfered somewhat with the work. There is a possibility of leakage from the feeder between the points of measurement at Glens Falls. No leakage was visible on the surface, but there is a large amount of leakage not far distant from the place of measurement. The measurements there indicate a gradual loss from the upper to the lower point of measurement.

The results of the rod comparisons agree more closely than those of meter with rods. It must not be concluded from the Rochester comparisons that because the rod discharges agree closely and the meter discharge differs from the rod discharge 7 per cent that this error is all due to the meter. The two sets of velocity measurements obtained with the meter during this comparison agree closely, whereas the time of run of the individual rods differs considerably. At least half of this difference is due to errors in the rod discharge measurements.

MURPHY'S EXPERIMENTS AT CORNELL UNIVERSITY.

In connection with the writer's experiments at Cornell University to determine the relative accuracy of measurements by the weir and by the current meter, the results of which are discussed on pages 58 to 95, surface velocity experiments were made with float rods and with the current meter, the results of which are given on pages 89 to 92.

FLOAT RODS AND WEIR.

FRANCIS'S EXPERIMENTS.

In 1856 J. B. Francis compared the discharge of a canal at Lowell, Mass., as found with float rods with that shown by a standard weir.[a] This wooden canal or flume was 27.75 feet wide where the first 63 experiments were made and 14 feet wide where the remaining 52

[a] Lowell Hydraulic Experiments, by J. B. Francis, p. 170.

experiments were made. The length of run was 70 feet, with a starting run of 28 feet. The time of run was obtained to a tenth of a second and the depth to 0.0001 foot. Every precaution was taken to obtain accurate results. The floats were tin tubes 2 inches in diameter, loaded at the lower end so as to float upright. They were put in the water at each foot of width of the canal, and the time of run was recorded on a chronograph. The observed velocities were plotted on cross-section paper and a mean curve was drawn among the points showing change in velocity from one side of the canal to the other. The mean velocity in the cross section was found from this curve by dividing the velocity area by the width. The variation of the observed velocities of individual rods from the velocity curve was from 8.57 per cent above to 11.4 per cent below this curve in experiment No. 1. The rods used were not all of the proper depth of immersion, and Francis derived the following formula for computing the correct discharge: $Q'''=Q''[1-0.116(\sqrt{D}-0.1)]$, in which Q'' is the measured discharge and D the depth of water in the flume less the depth of the immersed part of the rod and divided by the depth of water in the flume. After applying this formula he found that the variation of the rod discharge from the weir discharge for the 115 experiments is as follows: For 9 it is less than 0.1 per cent, for 79 it is less than 1 per cent, for 23 it is from 1 per cent to 1.9 per cent, for 2 it is from 2 per cent to 2.9 per cent, and for 1 it is 3.69 per cent. The mean velocity in these experiments varied from 0.5 foot to 5 feet per second.

CORNELL UNIVERSITY EXPERIMENTS.

At the close of the field work of the New York State canal survey of 1900 a series of experiments was made at the hydraulic laboratory of Cornell University for the purpose of comparing discharge as found with rods and current meter on the canals with that shown by the Cornell standard weir. These experiments were planned by the consulting engineer of the New York State canal survey, Mr. E. Kuichling, and were carried out, under the direction of Prof. G. S. Williams, in charge of the hydraulic laboratory, by the writer and by Mr. W. P. Boright, C. E., assisted by members of the class in hydraulics.

The surface level of the sections of the canals fluctuates rapidly on account of lockage of boats and irregular feed of water to lower sections. It was therefore necessary to make discharge measurements rapidly and to make short runs and starting runs. The depth of water in the different sections varied from 5 to 10 feet at the center, so that the immersed portion of the rods used varied from 75 per cent to 95 per cent of the depth of the water. The mean velocity varied from nearly 2 feet per second west of Lockport to 0 on the summit

levels. In the laboratory experiments the conditions were duplicated as closely as possible and the work was performed in the same way as on the canals, so that the results of the comparisons give a fair idea of the accuracy of the discharge measurements of the State canals and feeders.

Pl. II shows the laboratory canal and the observers employed in making the tests. A description of the laboratory and of the method of obtaining standard weir discharge will be found on pages 59 to 64. The gates at the head of the canal were opened until the head on the weir was such as to give the desired discharge; then the slits in the bulkhead and the height of the gates at the lower end of the canal were adjusted so as to give the desired depth of water in the channel. As soon as the flow became steady three parties began measuring the discharge of the canal, one with rods and two with current meters. Two series of rods were used, one of 75 per cent depth of immersion, the other of 90 per cent depth of immersion, the former lettered, the latter numbered, so that they could easily be recognized as they passed under each wire. The lengths of the run and of the starting run were the same as in the canal work, being from 25 to 7 feet for the former and from 10 to 8 feet for the latter, depending on the velocity. The number of rods used in an experiment varied from fifty to one hundred and fifty. Meter party No. 1 measured the discharge by the six-tenths-depth and the integration methods, and then assisted the rod-measuring party, four stop watches being used and the number of rods run in a given time nearly doubled. During each experiment the head on the weir, the depth of water in the canal, and the slope of the surface were read every thirty seconds and were checked occasionally by readings of the hook gage. The time of run of each rod was plotted on squared paper, using distance from side of canal as abscissæ and time of run, in seconds, as ordinates, and a mean time curve was drawn among them. The length of run divided by the mean ordinate of this curve gave the mean velocity, which multiplied by the cross-sectional area gave the discharge. The results of this rod-and-weir discharge comparison are given in the following table:

Comparison of float rod and weir velocity and discharge measurements at Cornell hydraulic laboratory.

Date.	Discharge over standard weir per second.	Rod gagings in laboratory canal.						Error of discharge referred to standard weir.		Mean error of discharge referred to standard weir.	
		Velocity from weir discharge per second.	Depth of water in canal.	Immersion, 75 per cent.		Immersion, 90 per cent.					
				Velocity per second.	Discharge per second.	Velocity per second.	Discharge per second.	75 per cent immersion.	90 per cent immersion.	75 per cent immersion.	90 per cent immersion.
1900.	*Cu. ft.*	*Feet.*	*Feet.*	*Feet.*	*Cu. ft.*	*Feet.*	*Cu. ft.*	*Per. ct.*	*Per. ct.*	*P. ct.*	*P. ct.*
October 24	214.588	1.428	9.356	1.422	213.674	.....	.....	+0.43	.....		
Do	140.514	0.945	9.253	0.962	142.966	0.949	141.034	−1.74	−0.37	1.32	0.75
Do	71.670	0.484	9.222	0.490	72.621	0.476	70.546	−1.33	+1.57		
Do	38.308	0.269	8.789	0.276	38.990	0.272	38.425	−1.78	−0.31		
October 26	178.553	1.473	7.543	1.510	183.185	1.525	184.832	−2.59	−3.52		
Do	125.298	1.033	7.549	1.080	131.000	1.058	128.332	−4.55	−2.42	3.96	2.09
October 27	61.272	0.510	7.471	0.530	63.658	0.520	62.457	−3.89	−1.93		
Do	30.089	0.254	7.376	0.266	31.543	0.255	30.239	−4.83	−0.50		
Do	196.387	1.983	6.163	2.067	204.695	2.044	202.407	−4.23	−3.06		
Do	132.408	1.308	6.299	1.363	137.956	1.341	135.730	−4.19	−2.51	4.22	2.95
Do	91.056	0.910	6.228	0.953	95.372	0.944	94.471	−4.74	−3.64		
Do	50.309	0.535	5.847	0.555	52.176	0.549	51.612	−3.71	−2.59		
October 31	198.258	1.475	8.365	1.537	206.554	1.507	202.523	−4.18	−2.15		
Do	125.299	0.930	8.393	0.958	129.174	.....	.....	−3.09	.....	4.68	2.78
October 29	65.287	0.486	8.355	0.512	68.766	0.501	67.288	−5.33	−3.07		
November 1	31.140	0.235	8.255	0.249	33.043	0.242	32.114	−6.11	−3.13		
										3.54	2.14

It is seen that the discharge obtained with the rods is larger for all depths, velocities, and percentage depths of immersion than the corresponding weir discharge, except in two cases. The greatest variation from the weir discharge is 6.11 per cent for the 75 per cent depth of immersion and 3.64 per cent for the 90 per cent depth of immersion. This variation from the weir discharge, or error, increases as the depth, velocity, and depth of immersion decrease. The mean error for all depths and velocities is 3.54 per cent for the 75 per cent depth of immersion and 2.14 per cent for the 90 per cent depth of immersion. The greatest variations from these means are +1.14 per cent and −2.22 per cent for the 75 per cent depth of immersion and +0.81 per cent and −1.39 per cent for the 90 per cent depth of immersion, a range of 3.4 per cent in the former and 2.2 per cent in the latter. From the last two columns is seen the extent to which the error increases as the depth decreases.

It is to be expected that the rod discharge will be greater than that of the weir, especially for the 75 per cent depth of immersion, for as the rods do not extend to the bottom they are not affected by the bottom layers of slowly moving water, and hence move faster than the mean velocity. By applying Francis's correction formula (p. 54) to these results others will be obtained agreeing more closely with those shown by the weir. It will be shown further on (p. 93) that the weir discharges used in these experiments and computed from Bazin's formula are probably too small by from 0.5 per cent to 2.5 per cent, the former for a head on weir of 1 foot, the latter for a head of 2.5 feet.

When these two sets of corrections are applied it will be found that the rod discharge is correct to within about 2 per cent. This degree of accuracy is only attained, however, by many observations, equivalent to six or twelve gagings, with the rods started 2 feet apart from side to side of canal.

CURRENT METER AND WEIR.

FTELEY AND STEARNS'S EXPERIMENTS.

Fteley and Stearns have made some comparisons of the discharge of the Sudbury conduit as obtained by weir measurement and by current meter.[a] The weir was of the sharp-crested type, 19 feet long, and was located at the head of the conduit. The flow to it was controlled by rectangular gates, which were changed slightly from time to time so as to keep the head on the weir constant. The current-meter measurements were made from a manhole in the conduit 6,000 feet below the weir. The meter used was a Fteley like that shown in fig. 5. Two methods of operating the meter were employed, viz, the point and the integration. When the point method was used the meter was held for thirty seconds at several points in the cross-sectional area, depending on the depth. For the greatest depth of 4.5 feet the number of points of observation was 167. The rate of moving the meter while integrating was from 0.1 foot to 1 foot per second. The results for the 8-vane meter are as follows:

Comparison of discharge measured with 8-vane Fteley meter and over weir.

No. of experiment.	Number of comparisons included in experiment.	Rate of integration.	Depth of center of meter from surface.	Ratio of speed of meter to speed of water.	Mean velocity of water.	Variation of meter discharge from weir discharge.
			Feet.		*Ft. per sec.*	*Per cent.*
1	1	0	1.5	0	1.83	+1.2
2	2	0	2.0	0	2.13	0.0
3	1	0	3.0	0	2.56	+0.1
4	1	0	4.0	0	2.83	+0.1
5	1	0	4.5	0	2.93	—0.4
6	1	0	3.0	0	1.71	—0.2
7	3	0.1	1.5	0.055	1.83	+0.8
8	3	0.1	2.0	0.047	2.13	+0.1
9	8	0.1	2.5	0.042	2.37	—0.6
10	3	0.1	3.0	0.039	2.56	—0.2
11	6	0.1	3.5	0.037	2.71	—0.1
12	4	0.1	4.0	0.035	2.83	—0.5
13	4	0.1	4.5	0.034	2.93	—0.8
14	4	0.1	2.5	0.042	2.37	+0.2
15	16	0.5	2.5	0.211	2.37	—3.6
16	15	0.5	3.5	0.185	2.71	—1.8
17	20	1.0	3.5	0.369	2.71	—6.5
18	3	0.1	3.0	0.058	1.71	—1.0
19	4	0.5	3.0	0.292	1.71	—4.5
20	7	1.0	3.0	0.585	1.71	—9.4

The results of experiments Nos. 2 to 6 show a remarkably close agreement between measurements by this meter and those over the

[a] Trans. Am. Soc. Civ. Eng., Vol. XII, p. 301.

weir. The length of an observation, thirty seconds, is too short to give a good average indication of the velocity. The discharge varied somewhat during the experiment. The depth of water in the conduit being small, any error in the depth must have introduced considerable error in the result. We would not expect, therefore, so close an agreement, which appears all the more remarkable when it is seen from the following table that the discharge shown by two weirs may differ by 3 per cent:

Values of m in formula $Q = mlh\sqrt{2gh}$, as found by Bazin and by Fteley and Stearns.[a]

Head on weir (h).	Values of m.		$m_1 - m_2$	$\frac{m_1 - m_2}{m_1}$
	Fteley and Stearns (m_2).	Bazin (m_1).		
Meters.	*Meters.*	*Meters.*	*Meters.*	*Per cent.*
0.1428	0.4149	0.4290	0.0141	3.29
0.1969	0.4166	0.4263	0.0097	2.28
0.2497	0.4191	0.4259	0.0068	1.60
0.3008	0.4218	0.4266	0.0048	1.12
0.3530	0.4247	0.4276	0.0029	0.68
0.3957	0.4272	0.4285	0.0013	0.33
0.4434	0.4296	0.4295	0.0001	0.02
0.4888	0.4323	0.4310	−0.0013	−0.33

It is seen that for heads on the weir of from 0.5 foot to 1 foot the variation in m is from 3 to 1 per cent.

MURPHY'S EXPERIMENTS.

The results of numerous weir, current-meter, and other experiments by the writer at the Cornell hydraulic laboratory are discussed in detail on the following pages; also the application of the results to ordinary river gaging and the general conclusions reached from these recent studies and investigations.

EXPERIMENTS AT CORNELL UNIVERSITY HYDRAULIC LABORATORY.

INTRODUCTORY.

This investigation was begun by the writer in May, 1900, while a fellow in civil engineering at Cornell University. It was interrupted from July 1 to December 4 of that year, on account of the New York State canal survey, in which the writer participated, and again from December 9 to April 1, on account of freezing weather, and was completed in May, 1901. Its object was to compare the discharge of the Cornell University experiment canal as obtained with a sharp-crested weir with that obtained with current meters operated by different

[a] Annales des ponts et chaussées, mémoires et documents, 1888, p. 416.

HYDRAULIC LABORATORY CANAL OF CORNELL UNIVERSITY, SHOWING CORPS ENGAGED IN MAKING DISCHARGE EXPERIMENTS.

methods, and thus determine the accuracy of velocity and discharge obtained by current-meter methods. The scarcity of meters available for the work, the lack of ready facilities for frequent testing and rating of the meters used, and the scarcity of water during the first months of the investigation render the results somewhat less valuable than they otherwise would be.

The writer takes this occasion to acknowledge his indebtedness to Mr. F. H. Newell, chief hydrographer of the United States Geological Survey, for his hearty cooperation; to Prof. E. A. Fuertes, director and dean of the College of Civil Engineering, Cornell University, for the use of the hydraulic laboratory and a chronograph, computing machine, current meter, and electric register, and for kindly interest in the work; to Prof. Gardener S. Williams, in charge of the hydraulic laboratory, for many valuable suggestions and for the use of a chart for converting head on the Cornell University standard weir into cubic meters; also to Mr. C. E. Torrance, scholar in civil engineering, to members of the senior class in civil engineering, and to Mr. C. D. Cass, assistant mechanician of the college, for their cheerful assistance.

DESCRIPTION OF CORNELL HYDRAULIC LABORATORY.

The Cornell hydraulic laboratory consists essentially, as shown in Pls. II, III, and IV and fig. 15, of a canal 16 feet wide, 10 feet deep, and 415 feet long, with concrete bottom and sides and with a bed slope of 1 foot in 500. There are six rectangular gates at the upper end for controlling water entering the canal and four gates near the lower end, two on each side, for controlling the depth of water in the canal. Fifty-nine feet below the entrance gates is a bulkhead about 10.5 feet high built of 12-inch by 12-inch timbers. On the top of this, or 11.1 feet above the bottom of the canal, is fastened a steel angle iron 3.5 inches by 5 inches by 16 feet long, with edges five-sixteenths inch thick, which forms the standard sharp-crested weir. The lower end of the canal is closed with 12-inch by 12-inch timbers, which can be moved up or down if desired and the water be allowed to pass out of the canal at the end instead of under the side gates. In the upper chamber are two sets of baffles for checking the velocity of the water after it passes under the entrance gates. One of these is 7.4 feet from the gates and is made of 4-inch by 12-inch timbers placed horizontally, with the wide face toward the current and spaced from 8 to 12 inches apart. On the upper side of these timbers are 1-inch by 6-inch strips, fastened diagonally and spaced 12 inches from center to center. The second baffle is about 6.5 feet below the first one and is similar in construction, except that the 1-inch by 6-inch strips are placed vertically and are spaced 10 inches from center to center Twenty-eight feet below the weir is a baffle made of 1-inch by 6-inch strips placed 3 inches from center to center, with the narrow side

toward the current. To still further quiet the waters after passing the weir, when the depth is small and the velocity large, a second baffle was constructed of 1-inch by 6-inch pieces placed vertically, spaced 2 inches from center to center and fastened on the upper side of the baffle just described.

Air is admitted under the falling sheet of water through 12-inch by 10-inch passages in the concrete, one on each side of the weir. The head on the weir and the depth of water in the canal are measured by piezometers and a hook gage. As rough checks on these readings gage boards and a dial gage were occasionally read. The piezometer for giving the head on the standard weir is formed of three 1-inch pipes (P, P, P, fig. 15) perforated for 3 feet of their length with $\frac{1}{4}$-inch holes 6 inches apart around the pipes. These are placed 27 feet upstream from the weir, with their axes parallel with the axis of the

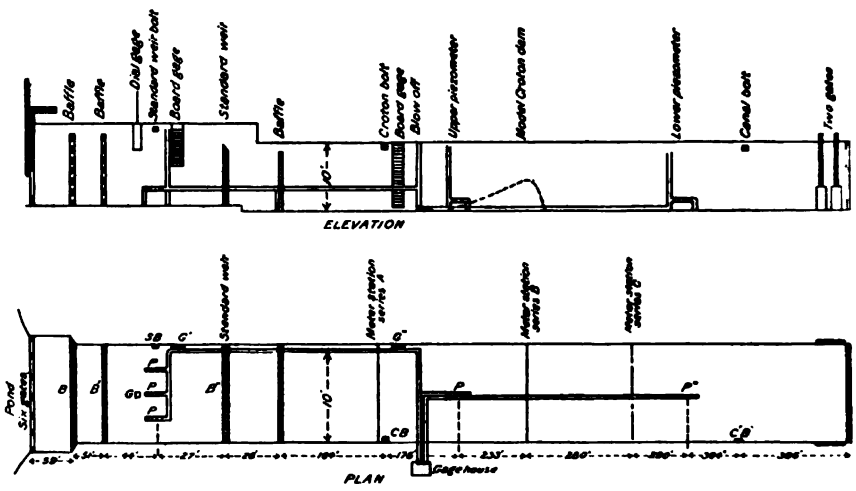

FIG. 15.—Plan and elevation of Cornell University experiment canal.

canal, 4 feet from the bottom, and each connected to a pipe which extends down the south side of the canal to a point opposite the gage house. From this point it is carried across the canal along the bottom and up into the gage house and is connected to a glass tube by a rubber hose. The tube is fastened to a scale marked to 2 mm. spaces. The canal piezometers are similar to those of the weir, but have only one entrance pipe, which is in the center of the canal. The surface elevation of the water was read with the hook gage at the three points in fig. 15 marked "Standard weir bolt," "Croton bolt," and "Canal bolt," the elevation of each of which is known. The dial gage and the board gage G' show approximately the head on the standard weir in feet and hundredths and enable the man operating the gates to keep a nearly constant head. A board gage (G'') opposite the "Croton bolt" (CB) shows approximately the depth of water in the canal.

FLUME, PENSTOCK, AND WHEEL HOUSE OF CORNELL HYDRAULIC LABORATORY CANAL.

SCOPE OF EXPERIMENTS.

The experiments naturally divide themselves into five groups, which we have called series A, B, C, D, and E. The experiments of series A were made at a section 158 feet below the standard weir and 75 feet upstream from a model of the Croton dam the height of which was 6 feet and the upstream face of which had a gradual slope and extended to within 29 feet of the meter station. This model dam formed a pool above it at the meter station and gave a zero velocity for 6 feet depth of water. The range of depths and velocities was therefore small. The water surface during the experiments was smooth, without boiling or swirls, with most of the foam made by the water falling over the weir moving down in two parallel lines 3 or 4 feet from each side. Three current meters were used in this series of experiments, viz, large Price meter No. 88, small Price meter No. 351, and the Cornell University Fteley meter. The latter was always held with a rod, the small Price meter was held with a cable, and the large Price meter with a cable in some of the experiments and with a rod in other experiments. About 3¼ inches of mud had accumulated on the bottom of the canal above the model dam. After the first two experiments the mud was removed for a space of 4 or 5 feet above and below the meter station. For all other experiments the bottom was clean and smooth.

The experiments of series B were made 234 feet below the standard weir and after the model dam had been removed. They are with high velocities and shallow depths, the scarcity of water at the time restricting the depth somewhat. In all these experiments except Nos. 6 and 8 the tail gates were open, so that there was no backwater. The surface of the water was quite rough, being a succession of waves, without swirls or boiling. (See Pl. IV.) The same three meters were used as in series A. The Fteley and the large Price were held with rods, the small Price was held with a rod in some of the experiments and with a cable in other experiments.

The experiments of series C were made 280 feet below the standard weir, as part of the tests of accuracy of the discharge measurements of the New York State canals and feeders made during the summer of 1900. They cover a range of depths from 6 to 9.5 feet and velocities from 0.23 foot to 2 feet per second. In most of the experiments of this series nearly all of the water was passed out of the canal through horizontal slits in the bulkhead. The water surface was comparatively smooth, being a succession of long waves, without boiling or swirls. Two meters were used—small Price No. 363, operated by the six-tenths-depth and integration methods, and small Price No. 351, operated by the ordinary method. The former was held with a cable, the latter with a rod.

The experiments of series D were made 220 feet below the standard weir, with Haskell meter No. 3 and small Price meter No. 363, each

held with a cable. The range of depth was from 5 to 9.5 feet, and the velocities from 0.25 foot to 2 feet. The water surface was like that in series C—long waves, without boiling or swirls. Three methods of obtaining velocity were used—the ordinary, the six-tenths, and the integration. This series is not complete, the work being stopped by the freezing of the canal. The piezometers could not be used on account of the freezing of the pipes. The hook gage only was used to measure the head on the weir and the depth of water in the canal.

The experiments of series E were made with two small Price meters and a Haskell meter, held with cables at station 220 feet below the standard weir. The depth in this series varied from 4.6 feet to 9.3 feet, and the mean velocity from 1.5 feet to 3 feet per second. It was designed to extend the results of the previous year to the higher velocities. The discharge measurements were made in pairs, as in series D, so as to compare the results of two meters with each other as well as the results of each meter with the corresponding weir discharge. The head on the weir and the elevation of water surface were obtained from readings of the portable hook gage. The water surface was quite rough for these higher velocities, being a succession of waves, without swirls. To quiet it and enable the surface elevation to be more accurately measured, in experiments 9 to 22 two planks, 2 inches by 12 inches by 15 feet long, were placed across the canal about 3 feet apart and 154 feet from the weir, fastened at the ends so as to float on the surface and break the force of the waves. In experiments 23 to 50 three of these planks were used. The planks served their purpose very well, but distorted somewhat the vertical velocity curves.

METHOD OF EXPERIMENTATION.

The first operation in each experiment was to adjust the entrance gates to admit such a quantity of water that with the desired depth of water at the meter station the velocity would be about the desired rate. The tail gates were then opened or closed somewhat, as the case required, until the water reached the desired depth and remained steady. The standard weir gage was then read every thirty seconds and the canal gages (one or both) were read every five minutes during the time the meter observations were being taken. When the hook gage was used it was read six times in succession, as quickly as possible, at each of the three points in fig. 15 marked "Standard bolt," "Croton bolt," and "Canal bolt," already described. When the ordinary method of operating the meter was used the meter was held at from two to six points, depending on the depth, in each of from five to eight verticals, and the number of the revolutions of the meter wheel in from one to two periods of from thirty to sixty seconds each was obtained. Usually it was two periods of fifty seconds each. In series C, ordinary method, one period of sixty seconds was used and the revolutions were read on a recorder. In all the other experiments except those

CORNELL HYDRAULIC LABORATORY CANAL, SHOWING DISTURBED WATER SURFACE DURING EXPERIMENTS IN SERIES B.

with the Fteley meter the revolutions were obtained from indications of an electric buzzer. When the meter was operated by the six-tenths-depth method it was held at about six-tenths depth below the surface in eight verticals, viz, 1, 3, 5, 7, 9, 11, 13, and 15 feet from the south side of the canal, and the revolutions were obtained for two periods of fifty seconds each. The meter was then held at the same depth in the same verticals in the inverse order, i. e., 15, 13, etc., 1 foot from the south side of the canal, and the revolutions were again counted for two periods of fifty seconds each. When the integration method was used in series C the meter was moved in the following way: It was started at 1 foot from the bottom (center of meter 0.5 foot above bottom) and 1 foot from the side of the canal, and was passed slowly to the surface at 4.5 feet from the side, then to the bottom at 8 feet from the side, then to the surface at 11.5 feet from the side, and then to the bottom at 15 feet from the side. The time at the beginning and end was noted and the total number of revolutions were counted. The meter was then carried back over the same path at about the same speed, and the time of passage and the number of revolutions were obtained as before. The mean time and the mean number of revolutions of these two passages across the canal are used as a single experiment. When this method was used in series A the meter was carried only once across the canal, and it was started and stopped at the bottom (center of meter 0.5 foot above bottom) and close to each side, and reached the surface 4 feet and 12 feet from the south side of the canal. When this method was used in series E the meter was moved slowly from the surface to the bottom (center of meter from 2.5 inches below surface to 5.5 inches above bottom) and back to the surface in each of the eight verticals in which the meter was held when the ordinary point method was used. The time of passage of the meter down and back again in each vertical was noted and the revolutions of the meter wheel were counted.

REDUCTION OF EXPERIMENTS.

The standard weir gage readings were averaged for the time of each discharge measurement, and the reading for zero head subtracted, giving the head on the weir in double centimeters. By means of a chart for converting head on weir into cubic meters per second and a computing machine the discharge in cubic feet per second was easily obtained. The depth of water in the canal was found by adding to the mean canal gage reading in feet the difference in elevation of the canal bottom and the zero of the scale. The discharge when the ordinary method was used was computed from the vertical velocity curve for that experiment (see figs. 23 to 28). The observations were usually taken in the eight verticals at 1, 3, 5, 7, 9, 11, 13, and 15 feet from the south side of the canal, and at the same distance above the bottom. When observations in any vertical were missing, as in ver-

ticals 7 and 11 in series C, they were supplied by interpolation. The mean number of revolutions at the depth of each observation for these eight verticals was then found, converted into velocity by the rating table, plotted (as in figs. 23 to 28), and a mean curve drawn. The mean abscissa of this curve is the mean velocity in the cross section; the discharge is the product of this velocity and the cross-sectional area.

When the six-tenths-depth method was used a horizontal curve of velocity was drawn in a similar manner and the mean velocity was found from it. The mean velocity by the integration method was obtained by dividing the revolutions by the corresponding time and converting the quotient into velocity.

DISCUSSION OF RESULTS.

COMPARISONS OF DISCHARGE MEASUREMENTS.

The following tables give the results of the discharge comparisons of series A to D. The standard weir discharge (third column) is the mean for the time over which the meter observations (ordinary method) extended. It is assumed to be the same for the shorter period of measuring the discharge by the six-tenths-depth and the integration methods. This is not strictly true for the larger discharges, but it is near enough for practical purposes. The true velocity is obtained by dividing the weir discharge by the cross-sectional area at the meter station. The other columns are self-explanatory.

Comparisons of discharge over Cornell University standard weir with measurements by current meters.

SERIES A.

Date.	No. of experiment.	Standard weir discharge (Q).	Meter observations.								Variation.	
			Depth of water in canal at meter section.	True velocity (V) at meter section.	Kind of meter.	Number of observations.	Ordinary method.		Integration method.			
							V_0	Q_1	V_1	Q_1	$\frac{Q-Q_0}{Q}$	$\frac{Q-Q_1}{Q}$
		Cu. ft. per sec.	*Feet.*	*Feet p. sec.*	(a)		*Feet p. sec.*	*Cu. ft. per sec.*	*Feet p. sec.*	*Cu. ft. per sec.*	*Per ct.*	*Per ct.*
1900.												
May 5...	1....	147.991	7.996	1.166	L. P. 88.	76	1.097	138.478	.....	.....	+ 6.43	.....
Do...	2....	65.024	7.167	0.573	....do...	29	0.447	50.714	.....	.....	+22.01	.....
May 7...	3....	78.481	7.258	0.683	Fteley .	31	0.677	77.780	.....	.....	+ 0.90	.....
May 8...	4....	162.684	8.104	1.268	S. P. 351.	38	1.267	162.464	1.252	160.62	+ 0.14	+1.26
Do...	5....	100.379	7.542	0.841	....do ..	20	0.790	94.318	.....	.....	+ 6.06	.....
May 9...	6....	193.624	8.369	1.462	....do...	35	1.435	190.109	.....	.....	+ 1.81	.....
Do...	7....	131.178	7.845	1.056	....do...	18	1.096	128.657	1.061	128.04	+ 1.92	+2.32
Do...	8....	131.037	7.848	1.056	L. P. 88.	18	0.982	122.000	1.006	124.96	+ 6.90	+4.63
Do...	9....	131.072	7.845	1.055	Fteley .	18	1.148	142.570	.....	.....	− 8.77	.....
May 15..	10....	148.556	7.984	1.175	....do...	40	1.286	162.540	.....	.....	− 9.43	.....
Do...	11....	119.947	7.729	0.980	S. P. 351.	32	0.939	114.887	0.978	119.66	+ 4.22	+0.26
May 16..	12....	74.137	7.281	0.643	L. P. 88.	36	0.533	61.433	.....	.....	+17.14	.....
Do...	13....	93.457	7.484	0.788	....do...	32	0.744	88.110	.....	.....	+ 5.72	.....
Do...	14....	74.137	7.280	0.643	Fteley .	29	0.642	73.985	.....	.....	+ 0.20	.....
Do...	15....	93.386	7.484	0.788	....do...	32	0.834	98.804	.....	.....	− 5.80	.....

[a] L. P. = large Price; S. P. = small Price. The figures given are the meter numbers.

Comparisons of discharge over Cornell University standard weir with measurements by current meters—Continued.

SERIES B.

Date.	No. of experiment.	Standard weir discharge (Q).	Meter observations.						Variation. $\frac{Q-Q_0}{Q}$
			Depth of water in canal at meter section.	True velocity (V) at meter section.	Kind of meter.	Number of observations.	Ordinary method.		
							V_0	Q_0	
		Cu. ft. per sec.	*Feet per sec.*	*Feet per sec.*	(a)		*Feet per sec.*	*Cu. ft. per sec.*	*Per ct.*
1900.									
May 19	1	50.366	1.115	2.823	S. P. 351	16	2.790	49.774	+ 1.11
Do	2	50.260	1.115	2.823	Fteley	16	3.599	64.206	−27.75
Do	3	50.154	1.110	2.824	L. P. 88	16	3.103	53.790	− 7.26
May 21	4	65.625	1.299	3.157	Fteley	24	3.344	69.502	− 5.91
Do	5	65.625	1.299	3.157	L. P. 88	24	3.085	64.118	+ 2.30
Do	6	66.896	2.000	2.091	Fteley	24	2.500	80.000	−18.09
Do	7	21.616	0.786	1.719	L. P. 88	16	1.538	19.341	+10.54
Do	8	66.731	2.029	2.056	....do...	24	1.900	61.682	+ 9.07
Do	9	33.060	0.741	2.766	Fteley	16	3.273	32.295	+ 2.30
May 22	10	21.369	0.550	2.428	....do...	16	2.945	25.916	−21.28
Do	11	94.410	1.885	3.130	....do...	24	3.789	114.250	−21.01
Do	12	94.410	1.885	3.130	L. P. 88	24	3.102	93.556	+ 0.90
Do	13	57.854	1.198	3.018	Fteley	24	3.720	71.305	−23.27
Do	14	57.854	1.198	3.018	L. P. 88	24	2.947	56.589	+ 2.18
Do	15	43.761	0.953	2.870	S. P. 351	16	2.698	43.055	+ 1.62
Do	16	43.761	0.953	2.870	Fteley	16	3.474	52.944	−20.98
Do	17	29.598	0.693	2.671	S. P. 351	16	2.425	26.876	+ 9.19
Do	18	29.598	0.693	2.671	Fteley	16	3.137	34.768	−17.47
Do	19	18.932	0.464	2.553	S. P. 351	8	2.290	16.983	−10.30
Do	20	18.932	0.464	2.553	Fteley	8	2.932	21.744	−14.84

[a] L. P. = large Price; S. P. = small Price. The figures given are the meter numbers.

Comparison of discharge over Cornell University standard weir with measurements by current meters.

SERIES C

Date.	Number of experiment.	Standard weir discharge (Q).	Meter observations.							Variation.		
			Depth of water in canal at meter section.	True velocity (V) at meter section.	Small Price No. 351, ordinary method.		Small Price No. 363.			Small Price No. 351, $\left(\frac{Q-Q_0}{Q}\right)$.	Small Price No. 363.	
					V_0	Q_0	Ordinary method. V_6	Ordinary method. Q_6	Integration method, (Q_1).		$\frac{Q-Q_6}{Q}$	$\frac{Q-Q_1}{Q}$
1900.		*Cu. ft. per sec.*	*Feet.*	*Ft. per. sec.*	*Ft. per sec.*	*Cu. ft. per sec.*	*Ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Per cent.*	*Per cent.*	*Per cent.*
October 24	1	216.131	9.460	1.409	1.446	219.836	1.465	222.980	220.398	− 1.77	−4.11	− 0.63
Do	2	140.515	9.374	0.932	0.969	146.060	0.985	148.528	143.099	− 4.13	−6.13	− 5.37
Do	3	71.681	9.338	0.477	0.493	73.050	0.487	73.167	71.514	− 2.38	−2.08	− 1.59
Do	4	38.254	8.910	0.265	0.259	37.420	0.278	40.113	33.330	+ 2.03	−6.00	−16.16
October 26	5	178.553	7.673	1.444	1.449	179.130	1.489	184.075	174.679	− 0.53	−3.09	− 5.17
Do	6	125.298	7.640	1.018	0.999	122.974	1.047	128.880	120.789	+ 1.85	−2.78	− 5.12
October 27	7	61.272	7.582	0.502	----------	----------	0.522	63.771	61.327	----------	−4.88	− 4.08
Do	8	31.176	7.557	0.255	0.215	26.180	0.258	31.488	28.070	+16.01	−1.04	−22.10
Do	9	50.310	6.005	0.515	0.494	48.208	0.540	52.696	46.451	+ 4.17	−5.92	− 7.65
Do	10	196.387	6.278	1.940	1.890	192.799	1.989	201.367	188.232	+ 1.83	−1.46	− 4.86
Do	11	132.414	6.399	1.283	1.251	129.078	1.318	135.991	123.816	+ 2.52	−3.18	− 4.27
Do	12	91.056	6.319	0.893	0.847	86.318	0.920	93.758	83.872	+ 5.20	−5.08	− 2.96
October 29	13	65.319	8.476	0.478	0.464	63.325	0.492	67.146	60.459	+ 3.07	−2.35	− 2.80
October 31	14	198.258	8.470	1.454	1.460	199.115	1.514	206.480	187.795	− 0.44	−3.71	− 6.76
Do	15	125.301	8.508	0.915	0.890	121.921	0.949	130.001	114.522	+ 2.69	−3.75	− 9.54
November 1	16	31.223	8.455	0.229	0.201	27.364	0.240	32.674	25.186	+12.37	−2.47	−39.30

Comparison of discharge over Cornell University standard weir with measurements by current meters—Continued.

SERIES D.

Date.	Number of experiment.	Standard weir discharge (Q).	Meter observations.							Variation.		
			Depth of water in canal at meter section.	True velocity (V) at meter section.	Kind of meter.[a]	Ordinary method.		Six-tenths-depth method (Q_6).	Integration method (Q_1).	$\frac{Q-Q_0}{Q}$	$\frac{Q-Q_6}{Q}$	$\frac{Q-Q_1}{Q}$
						V_0	Q_0					
1900.		*Cu. ft. per sec.*	*Feet.*	*Ft. per sec.*		*Ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Per cent.*	*Per cent.*	*Per cent.*
December 6	1	233.262	9.505	1.528	S. P. 363	1.519	231.976		235.082	+0.55		−0.77
Do	2	233.262	9.505	1.528	Hask. 3	1.484	226.380		239.968	+2.95		−2.88
December 7	3	229.731	9.317	1.535	do			239.120	235.828		− 4.09	−2.66
Do	4	117.673	[b] 9.536	0.768	do	0.832	[b] 127.421	[b] 126.498		−8.28	− 7.50	
Do	5	117.673	[b] 9.536	0.768	S. P. 363	0.794	[b] 121.601	[b] 119.301		−3.34	− 1.40	
Do	6	95.176	[b] 9.524	0.622	Hask. 3	0.676	[b] 103.401	[b] 105.846		−8.63	−11.21	
Do	7	95.176	[b] 9.524		S. P. 363	0.563	[b] 99.883	[b] 97.892		−4.93	− 2.84	
December 8	8	221.749	7.245	1.905	Hask. 3	1.864	216.932	218.680	228.340	+2.13	+ 1.38	−3.08
Do	9	221.749	7.245	1.905	S. P. 363	1.867	217.281	222.521		+2.01	− 0.35	
Do	10	191.165	7.217	1.649	Hask. 3	1.675	194.183	200.209	202.647	−1.58	− 4.73	−6.00
Do	11	191.165	7.217	1.649	S. P. 363	1.651	191.400	192.793		+0.20	− 0.84	
Do	12	110.186	7.183	0.955	Hask. 3	1.022	117.919	118.802	119.609	−7.01	− 7.84	−8.55
Do	13	110.186		0.955	S. P. 363	0.955	110.188	110.858		0.00	− 0.68	
Do	14	56.717	7.113	0.496	Hask. 3			53.244			− 6.14	
					S. P. 363			58.270			− 2.73	
Do	15	57.071	5.154	0.689	Hask. 3	0.730	60.455	62.277	62.277	−5.94	− 9.10	−9.10
Do	16	57.071	5.154	0.689	S. P. 363	0.672	55.651	57.308		+2.49	− 0.42	

[a] S. P. = small Price; Hask. = Haskell. The figures given are the meter numbers.

[b] Hook gage broken; depth not accurately measured.

It is seen from the foregoing tables that the meter discharge differs from the weir discharge all the way from 0 to 40 per cent. One might say, without careful examination, that the current meter must be a very unreliable velocity-measuring instrument; but when we examine these results carefully and plot them according to velocity we find the case very different. Take first the results by the ordinary method.

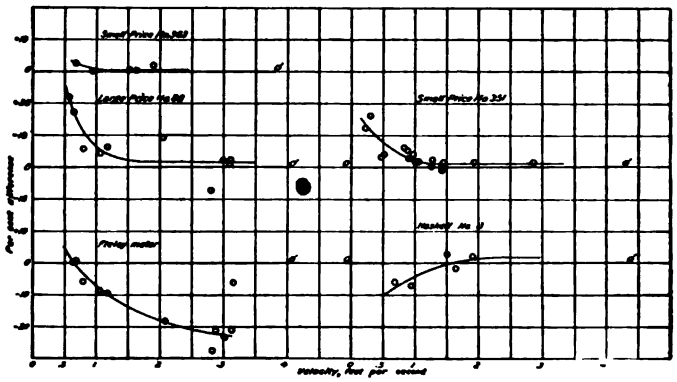

FIG. 16.—Diagram showing difference between meter discharge by ordinary method and weir discharge, from measurements in Cornell University experiment canal. Line 0-0′ represents weir discharge.

These are plotted for each meter in fig. 16, using mean velocity as abscissæ and percentage difference as ordinates. It is seen that nearly all of these points fall on well-defined lines. The few exceptions are those in which the depth is small and the errors of depth and position of meter have a large effect on the measured discharge. The discharge obtained with the Fteley meter differs more from the corre-

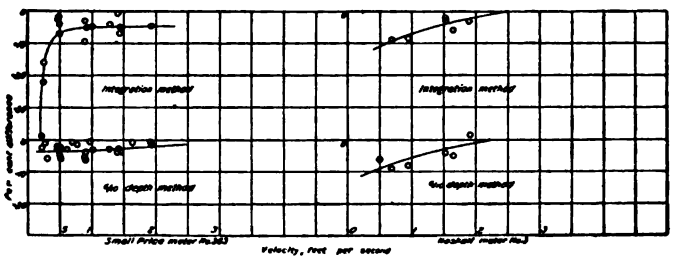

FIG. 17.—Diagram showing difference between meter discharge by six-tenths-depth and integration methods and weir discharge, from measurements in Cornell University experiment canal. Line 0-0′ represents weir discharge.

sponding weir discharge than that obtained with the other meters. This is because it had never been rated. The constant we have used in reducing the observations with this meter—viz, 1 revolution per second at 1 foot velocity = 1.072—was obtained from observations by students. It is not, however, much in error for this velocity, but is largely in error for other velocities. The rating obtained from these weir experiments is given in the table on page 81. For the other

three meters the percentage error is small for velocities above 1 foot per second. For the Price meters the error is positive and increases rapidly as the velocity decreases. For the Haskell meter the error is negative and increases, negatively, rapidly as the velocity decreases. The error in rating, if we may call it such, is not so large as it appears from these diagrams, for a 10-per cent error in a small quantity is only a 1-per cent error in a quantity ten times as large. The rating tables as derived from these curves and as found by moving the meter through still water are given in the table on page 81. Experiments with depths of 0.75 foot or less (Nos. 9 and 17 to 20 of series B) are not plotted in the diagram (fig. 16), as the probable error is large; nor are experiments 1 to 4 of series C, because the upper and lower parts of the vertical curves are not well defined; nor experiments 4 to 7 of series D, because there appears to be an error in the hook-gage work of those experiments.

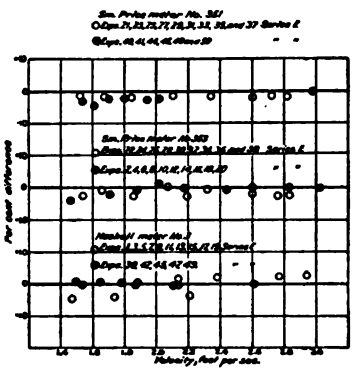

FIG. 18.—Diagram showing difference between meter discharge with different meters and weir discharge in experiments of series E in Cornell University experiment canal. Zero line indicates weir discharge.

In fig. 17 are plotted the percentage differences between weir discharge and discharge obtained by the six-tenths-depth and the integration methods. It is seen that the meter discharge by these methods is greater than the weir discharge, being 4 or 5 per cent greater for velocities above 1 foot per second. In the integration method, for small velocities the difference increases very rapidly as the velocity decreases. It is seen from figs. 16 and 17 that while the ordinary method gives discharge 1 or 2 per cent less than the weir for velocities above 1 foot per second, the six-tenths-depth and the integration methods give discharge 4 or 5 per cent greater than the weir.

The results of the discharge measurements of series E are given in the following table and are plotted in fig. 18, which shows three sets of double comparisons. Experiments 1 to 20 give a comparison of simultaneous measurements with small Price meter No. 363 and Haskell meter No. 3, and also with the discharge obtained at the same time with the weir. Experiments 21 to 38 give similar comparisons for the two small Price meters and the weir, and experiments 39 to 50 give similar comparisons for Haskell and Price meters and the weir.

Comparison of discharge over Cornell University standard weir with measurements by current meters.

SERIES E.

No. of experiment.	Date.	Depth of water in canal at meter section.	True velocity at meter section.	Standard weir discharge (Q).	Meter discharge (Q_w).	Variation $\left(\frac{Q-Q_w}{Q_w}\right)$.	Kind of meter.[a]	Difference in meter discharges.
	1901.	*Feet.*	*Ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Per cent.*		*Per cent.*
1	April 1	9.075	1.472	204.41	214.08	−4.73	Hask. 3	0.86
2	do	9.075	1.456	204.41	212.33	−3.87	S. P. 363	
3	April 2	6.079	2.208	208.88	216.28	−3.54	Hask. 3	0.99
4	do	6.079	2.187	208.88	214.22	−2.55	S. P. 363	
5	do	7.453	1.744	200.81	208.85	−4.00	Hask. 3	2.03
6	do	7.453	1.710	200.81	204.77	−1.97	S. P. 363	
7	do	5.742	2.137	197.64	197.02	−0.31	Hask. 3	1.58
8	do	5.742	2.171	197.64	200.15	+1.27	S. P. 363	
9	April 5	7.409	1.869	222.67	222.68	0.00	Hask. 3	0.75
10	do	7.409	1.883	222.67	224.35	−0.75	S. P. 363	
11	do	6.295	2.137	220.33	216.00	+1.96	Hask. 3	1.82
12	do	6.295	2.177	220.33	220.03	+0.14	S. P. 363	
13	do	5.628	2.377	219.38	214.82	+2.08	Hask. 3	2.51
14	do	5.628	2.438	219.38	220.33	−0.43	S. P. 363	
15	do	5.294	2.611	221.96	222.02	−0.03	Hask. 3	0.34
16	do	5.294	2.602	221.96	221.27	+0.31	S. P. 363	
17	do	4.892	2.764	222.81	217.32	+2.46	Hask. 3	2.22
18	do	4.892	2.827	222.81	222.27	+0.24	S. P. 363	
19	do	4.617	2.936	224.75	218.32	+2.86	Hask. 3	2.85
20	do	4.617	3.019	224.75	224.50	+0.01	S. P. 363	
								1.60
21	April 6	4.808	2.985	230.36	230.66	−0.13	S. P. 351	0.71
22	do	4.808	3.006	230.36	232.30	−0.84	S. P. 363	
23	April 10	8.744	1.670	230.75	234.68	−1.70	S. P. 351	0.71
24	do	8.744	1.657	230.75	232.85	−0.99	S. P. 363	
25	do	7.874	1.846	229.28	233.61	−1.89	S. P. 351	0.88
26	do	7.874	1.862	229.28	235.64	−2.77	S. P. 363	
27	do	6.889	2.108	229.91	233.25	−1.45	S. P. 351	1.68
28	do	6.889	2.073	229.91	229.38	+0.23	S. P. 363	
29	April 11	6.129	2.340	227.16	230.25	−1.36	S. P. 351	0.85
30	do	6.129	2.320	227.16	228.28	−0.50	S. P. 363	
31	do	5.483	2.596	225.01	228.59	−1.60	S. P. 351	0.31
32	do	5.483	2.604	225.01	229.30	−1.91	S. P. 363	
33	do	5.185	2.725	224.06	226.98	−1.30	S. P. 351	1.23
34	do	5.185	2.758	224.06	229.73	−2.53	S. P. 363	
35	do	5.003	2.816	222.60	226.37	−1.69	S. P. 351	0.65
36	do	5.003	2.834	222.60	227.82	−2.34	S. P. 363	
37	do	9.256	1.522	223.40	226.38	−1.33	S. P. 351	1.05
38	do	9.256	1.538	223.40	228.71	−2.38	S. P. 363	
								0.90
39	April 12	9.344	1.486	224.63	223.11	+0.68	Hask. 3	3.68
40	do	9.344	1.541	224.63	231.37	−3.00	S. P. 351	
41	do	8.934	1.613	221.39	231.58	−4.60	S. P. 351	4.67
42	do	8.934	1.543	221.39	221.53	+0.07	Hask. 3	
43	do	8.297	1.646	221.39	219.50	+0.81	do	3.21
44	do	8.297	1.700	221.39	226.70	−2.40	S. P. 351	
45	do	7.806	1.775	221.49	222.69	+0.54	Hask. 3	2.61
46	do	7.806	1.803	221.49	226.19	−2.07	S. P. 351	
47	do	7.266	1.879	221.21	219.34	+0.85	Hask. 3	3.38
48	do	7.266	1.943	221.21	226.81	−2.53	S. P. 351	
49	do	6.439	2.132	221.03	220.43	−0.27	Hask. 3	1.80
50	do	6.439	2.182	221.03	225.61	−2.07	S. P. 351	
								3.22

[a] S. P. = small Price; Hask. = Haskell. The figures given are the meter numbers.

The principal results of the foregoing comparisons have been condensed in the following table:

Table showing percentage variation between weir discharge and meter discharge, and between meter discharge by different instruments of experiments in series E.

Experiments.	Kind of meter.	Difference between standard weir discharge and meter discharge.				Difference in discharge of simultaneous meter measurements.			
		Max.	Min.	Mean.[a]	Range.	Max.	Min.	Mean.	Range.
		Per ct.	*Per ct.*	*Per ct.*	*Per cent.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
1 to 20	Haskell No. 3	−4.73	0.00	−0.33	−4.73 to +2.86	.....	.....	.....	.....
Do	S. Price No. 363	−3.87	+0.01	−0.76	−3.87 to +1.27	2.85	0.34	[a] 0.29 [b] 1.60	2.51
21 to 38	S. Price No. 351	−1.89	−0.13	−1.38	−1.89 to −0.13	.....	.....	.....	.....
Do	S. Price No. 363	−2.77	+0.23	−1.56	−2.77 to +0.23	1.68	0.31	[a] 0.18 [b] 0.90	1.37
39 to 50	S. Price No. 351	−4.60	−2.07	−2.78	−4.60 to −2.07	.....	.....	.....	.....
Do	Haskell No. 3	+0.85	−0.27	+0.40	+0.85 to −0.27	4.67	1.80	[a] 3.22 [b] 3.22	2.87

[a] Regarding signs. [b] Disregarding signs.

It is seen from this that in none of these fifty experiments does a meter discharge differ from a corresponding weir discharge 5 per cent, and in no case do two simultaneous meter discharges differ from each other 5 per cent. In experiments 1 to 20 the mean variation from the weir discharge is −0.33 per cent for the Haskell meter and −0.76 per cent for the Price meter, while the mean difference between corresponding meter discharges is 0.29 per cent. In experiments 21 to 38 the mean variation from the weir discharge is 1.38 per cent for Price meter No. 351 and −1.56 per cent for Price meter No. 363, while the mean difference between corresponding meter discharges is 0.18 per cent. In experiments 39 to 50 the mean variation from the weir discharge is 2.78 per cent for the Price meter and 0.40 per cent for the Haskell meter, while the mean difference between corresponding meter discharges is 3.22 per cent.

The range of variation of meter discharge from weir discharge is greater than that of corresponding meter discharges. This is to be expected, however, since there are a number of possible errors in the former which are not in the latter. Errors in measuring head, depth, calibration of weir, velocity, and rating of meter affect the former, while only the two latter errors affect corresponding meter discharges.

It is also seen that the mean of the difference between simultaneous discharge measurements Nos. 21 to 38 is only 0.18 per cent, and the extreme range in these eighteen consecutive measurements is only 1.37 per cent. How much of this error is due to errors in the rating table and how much to errors in observing velocity we were unable to determine, as good facilities for rating were not at hand. We are, however, justified by these experiments in the statement that the discharge of this canal can, with a small Price meter, be measured to within less than 1 per cent when the mean velocity in the canal is from 1.5 feet to 3 feet per second.

VELOCITY CURVES.

Curves of equal velocity in the cross-sectional area of observation are shown in figs. 19, 20, 21, and 22. Four experiments are selected (one from each series) from the sixty-five experiments of series A to D by the ordinary method, to show the variation of velocity in the sections. They are self-explanatory. Fig. 20 illustrates a case of small depth, high velocity, and no back-water effect. The maximum velocity is at the surface, nearly midway between the banks. In figs. 19, 21, and 22 the maximum velocity is below the surface and not midway between the banks. It is less at the center than 3 or 4 feet from either side. This is true of all the experiments of series A. We tried admitting the water to the upper chamber of the canal in various ways, by opening some of the gates and closing or partly closing others, but the distribution of velocity appeared to be nearly independent of the openings through which the water was admitted to the canal.

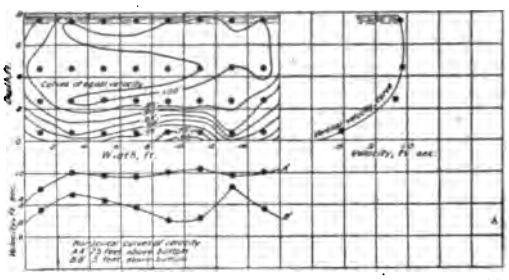

FIG. 19.—Curves of equal velocity in experiment No. 11, series A.

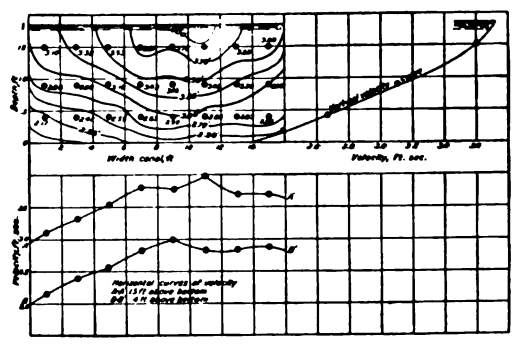

FIG. 20.—Curves of equal velocity in experiment No. 12, series B, with large Price meter No. 88.

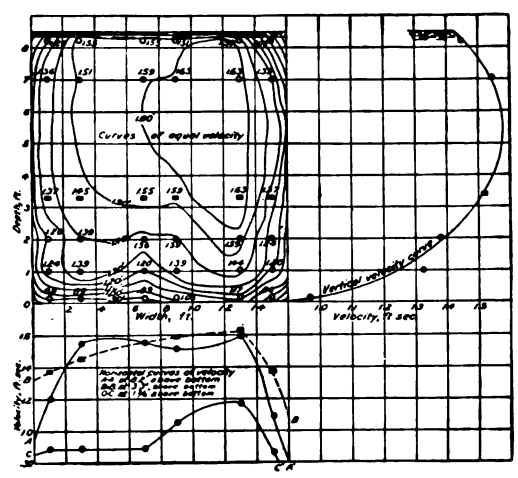

FIG. 21.—Curves of equal velocity in experiment No. 14, series C. The dots are for small Price meter No. 351; heavy black squares for small Price meter No. 363.

Horizontal velocity curves are shown in these same figures (19 to 22), the velocity curve at six-tenths depth below the surface being shown, and also the curves for surface and bottom. In these figures the velocity

near the north side of the canal is somewhat less than that near the south side. This is true of all the experiments of series C and D. It is due to the north side of the canal being much rougher than the south side, the concrete of the north side having been cut away preparatory to its repair just previous to making the experiments of series C.

Vertical velocity curves for these four series of experiments (A to D) are shown in figs. 23 to 28. Each of these curves is the mean of observations in the eight verticals 1, 3, 5, 7, 9, 11, 13, and 15 feet from the south side of the canal. For series C and D, figs. 26, 27, and 28, the observations obtained with small Price meter No. 363 at six-tenths depth are shown by the little squares. As a rule they fall outside the curve, meter No. 363 indicating a somewhat greater velocity than meter No. 351. This fact is also shown by the corresponding curves of figs. 16 and 17. The two sets of velocity curves (full and dotted) of fig. 28 were found from simultaneous velocity measurements. Two parties measured velocity in the same section at the same time. One party, with the Haskell meter, started near the south side of the canal and worked toward the north side; the other party, with the Price meter, started at the north side and worked toward the south side. It is seen from these curves (fig. 28) that the bottom velocities agree more closely than those at the surface, and that the Haskell meter gives a much larger surface velocity than the Price meter. We should expect a little difference, since the revolving head

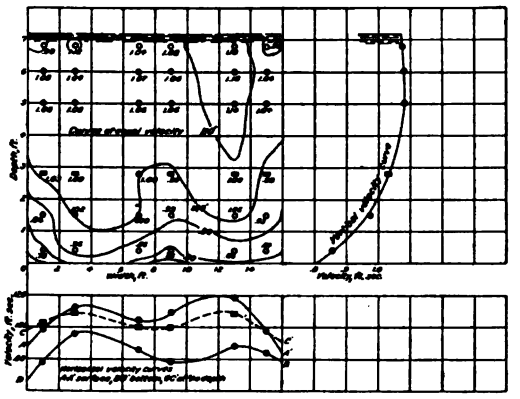

FIG. 22.—Curves of equal velocity in experiment No. 20, series D. The dots are for Haskell meter No. 3; heavy black squares for small Price meter No. 363.

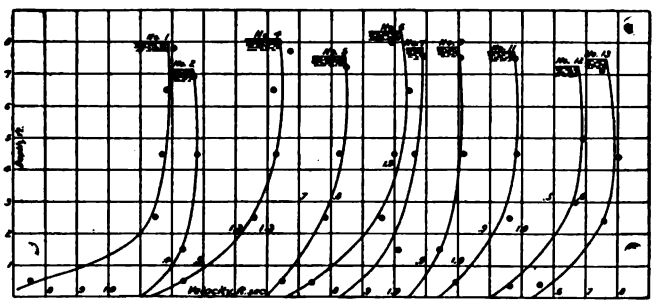

FIG. 23.—Vertical velocity curves obtained with current meters in experiments in series A. Nos. 1, 2, 8, 12, and 13 are for large Price meter No. 88; Nos. 4, 5, 6, 7, and 11 are for small Price meter No. 351.

of the Haskell meter is larger than the wheel of the Price meter, and its center being farther below the surface it must revolve faster. But the difference in velocity is much greater than this little difference in depth of axis would indicate. (See p. 91.)

The shape of these curves evidently depends on the depth and velocity. For depths not exceeding 1 foot it is a nearly straight line,

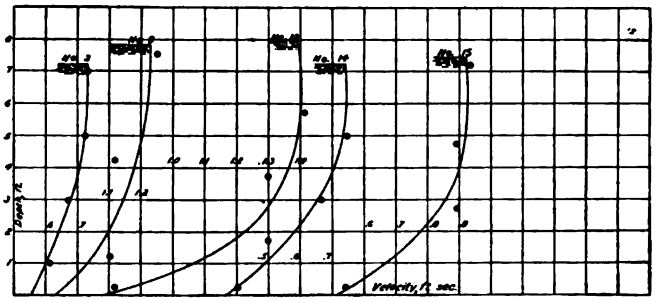

FIG. 24.—Vertical velocity curves obtained with Fteley current meter in experiments in series A.

with the maximum velocity at the surface and the mean velocity at mid depth. For depths of 8 or 9 feet and small velocities the curve is very flat, with the maximum velocity at two-tenths to three-tenths depth and the mean velocity at sixty-five-hundredths to seven-tenths depth below the surface. The radius of curvature decreases as the velocity increases. In all of these curves the least velocity is at the bottom. Nos. 6 and 8, series B, fig. 25, show the effect on the vertical

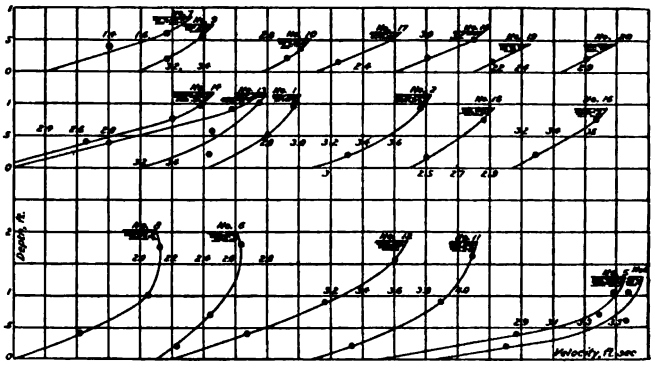

Fig. 25.—Vertical velocity curves obtained with current meters in experiments in series B. Nos. 1, 15, 17, and 19 are for small Price meter No. 351; Nos. 3, 5, 7, 8, 12, and 14 are for large Price meter No. 88; Nos. 2, 4, 6, 9, 10, 11, 13, 16, 18, and 20 are for Fteley meter.

velocity curve of checking the discharge at the lower end of the canal. For all the other curves of fig. 25 there is free discharge. The effect of checking the discharge at the lower end is to force the thread of maximum velocity from the surface to a depth of two-tenths or more. The table on page 77 gives the position of the threads of maximum and mean velocity taken from the curves shown in figs. 23 to 28. It is

difficult to locate the threads with accuracy, since very little change in the shape of the curve would make a great change in the position of the threads. It is easily seen that the shape may be changed somewhat and yet fit the observations nearly as well as the one drawn and give a discharge differing from it but little. For velocities of a foot or more per second, however, the threads can be located with a fair

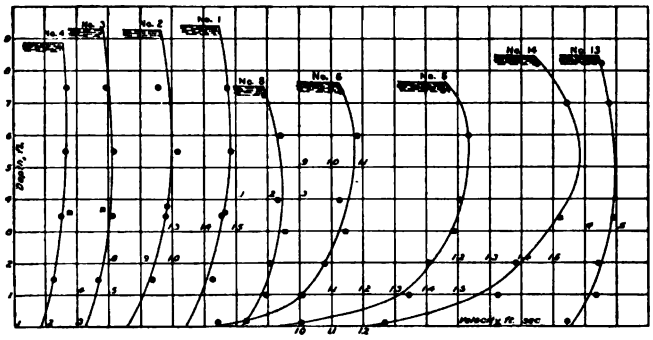

FIG. 26.—Vertical velocity curves obtained with current meters in experiments in series C. Heavy round dots are for small Price meter No. 351: the square blocks are for small Price meter No. 363.

degree of accuracy. The position of the thread of maximum velocity as found from series A is eighteen-hundredths depth below the surface; for series B it is one-tenth depth; for series C, thirty-eight-hundredths depth; and for series D, twenty-four-hundredths depth. For the mean of C and D, in which the conditions are nearly the same, it is thirty-one-hundredths depth. The position of the thread of mean

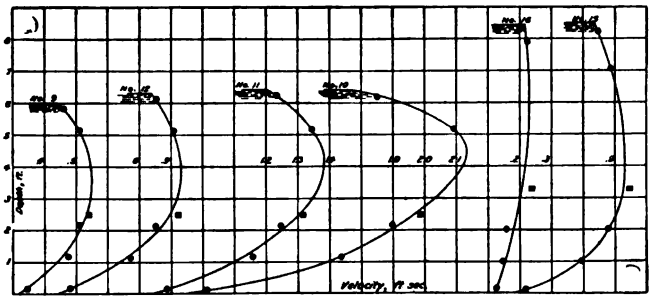

FIG. 27.—Vertical velocity curves obtained with current meters in experiments in series C. Heavy round dots are for small Price meter No. 351; the square blocks are for small Price meter No. 363.

velocity as shown by this table is sixty-six-hundredths depth for series A, fifty-four-hundredths depth for series B, and sixty-six-hundredths depth for series C and D. It is seen that the threads of mean and maximum velocity are nearer the surface in series A than in series C or D, although the depths do not differ much. This is probably due to the influence of the Croton model dam, the long upstream slope of

which has had the effect of forcing the thread of maximum velocity up to thirteen-hundredths depth. As the ratio of width to depth

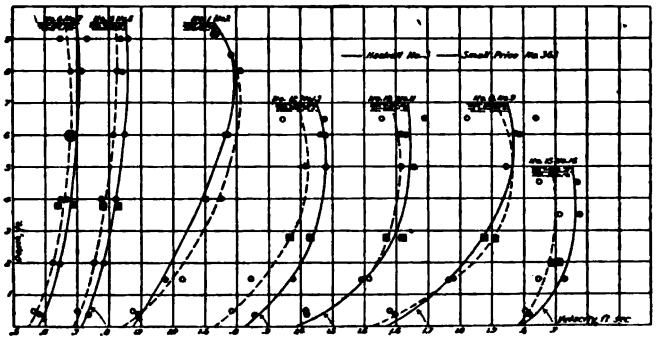

FIG. 28.—Vertical velocity curves obtained with Haskell meter No. 3 and small Price meter No. 363 in experiments in series D. Open circles are for small Price meter No. 363, point method; heavy black dots are for Haskell meter No. 3, point method; heavy black squares are for small Price meter No. 363, six-tenths-depth method.

changed from 16 to 2 the thread of mean velocity moved from fifty-four-hundredths depth to sixty-six-hundredths depth below the surface.

Table showing position of threads of maximum and mean velocity in Cornell University experiment canal as found from current-meter discharge measurements made in May, November, and December, 1900.

No. of experiment.	Series A.				Series B.				Series C.				Series D.			
	Velocity (V).	Depth (D).	Ratio $\left(\frac{dm}{D}\right)$.	Ratio $\left(\frac{d'}{D}\right)$.	Velocity (V_0).	Depth (D).	Ratio $\left(\frac{dm}{D}\right)$.	Ratio $\left(\frac{d'}{D}\right)$.	Velocity (V_0).	Depth (D).	Ratio $\left(\frac{dm}{D}\right)$.	Ratio $\left(\frac{d'}{D}\right)$.	Velocity (V_0).	Depth (D).	Ratio $\left(\frac{dm}{D}\right)$.	Ratio $\left(\frac{d'}{D}\right)$.
	Feet per second.	*Feet.*			*Feet per second.*	*Feet.*			*Feet per second.*	*Feet.*			*Feet per second.*	*Feet.*		
1	1.17	8.00	0.81	0.35	2.79	1.12	1.00	0.40	1.45	9.46	0.65	0.31	1.52	9.51	0.75	0.29
2	0.57	7.17	0.77	0.29	3.60	1.12	1.00	0.49	0.97	9.37	0.61	0.32	1.48	9.51	0.80	0.47
3	0.68	7.26	0.92	0.28	3.10	1.11	1.00	0.49	0.49	9.34	0.52	0.27	.....	9.32	.....	.....
4	1.27	8.10	0.89	0.29	3.34	1.30	1.00	0.42	0.26	8.92	0.62	0.28	0.83	9.54	0.79	0.42
5	0.84	7.54	0.80	0.49	3.09	1.30	1.00	0.38	1.45	7.67	0.70	0.33	0.79	9.54	0.84	0.42
6	1.46	8.37	0.75	0.30	2.50	2.00	0.85	0.44	1.00	7.64	0.72	0.33	0.68	9.52	0.77	0.39
7	1.06	7.85	0.84	0.45	1.54	0.79	1.00	0.45	.....	7.58	.....	.....	0.65	9.52	0.80	0.34
8	1.06	7.85	0.75	0.31	1.90	2.03	0.85	0.37	0.22	7.56	0.60	0.28	1.86	7.25	0.82	0.36
9	1.06	7.85	0.95	0.43	3.27	0.75	1.00	0.47	0.49	6.01	0.60	0.28	1.87	7.25	0.69	0.32
10	1.18	7.98	0.79	0.37	2.95	0.55	1.00	0.50	1.89	6.28	0.71	0.32	1.68	7.22	0.77	0.34
11	0.98	7.73	0.71	0.36	3.79	1.89	1.00	0.40	1.25	6.40	0.66	0.32	1.65	7.22	0.72	0.33
12	0.64	7.28	0.75	0.30	3.10	1.89	1.00	0.43	0.85	6.32	0.60	0.31	1.02	7.18	0.72	0.33
13	0.79	7.48	0.65	0.21	3.72	1.20	1.00	0.46	0.46	8.48	0.56	0.27	0.96	7.18	0.70	0.36
14	0.64	7.28	0.86	0.39	2.95	1.20	1.00	0.49	1.46	8.47	0.65	0.31	.....	7.11	.....	.....
15	0.79	7.48	0.84	0.33	2.70	0.95	1.00	0.48	0.89	8.51	0.53	0.27	0.73	5.15	0.70	0.33
16	.....	.....	.....	.....	3.47	0.95	1.00	0.48	.....	.....	0.623	0.30	0.67	5.15	0.70	0.44
17	.....	.....	.....	.....	2.43	0.69	1.00	0.50	.....	.....	0.755	0.37	.....	.....	.....	.....
18	.....	.....	.....	.....	3.14	0.69	1.00	0.50	.....	.....	.....	.....	.....	.....	.....	.....
19	.....	.....	.....	.....	2.29	0.46	1.00	0.50	.....	.....	.....	.....	.....	.....	.....	.....
20	.....	.....	.....	.....	2.93	0.46	1.00	0.50	.....	.....	.....	.....	.....	.....	.....	.....
	.....	.....	0.815	0.343	.....	.....	0.985	0.457	.....	.....	0.69	0.34	.....	.....	0.755	0.37

V = velocity found from the weir.
V_0 = velocity found with meter by ordinary method.
dm = distance above bottom to thread of maximum velocity.
d' = distance above bottom to thread of mean velocity.

The first of the following tables gives the mean, maximum, and bottom velocities in the experiments of series A, C, and D, also the ratio of bottom velocity to mean velocity and of mean velocity to mid-depth velocity. It is seen that the ratio of mean velocity to mid-depth velocity is much more nearly constant, and hence is better to use than that of mean velocity to bottom velocity. The second table gives the ratio of mean velocity to three-tenths-depth velocity, and of mean velocity to six-tenths-depth velocity in series A, C, and D. The ratio at three-tenths depth is seen to be more nearly constant than that at six-tenths depth.

Velocities at various depths and velocity ratios in Cornell University experiment canal as found from standard weir and current-meter discharge measurements.

No. of experiment.	Series A. Depth (D) in feet.	Velocities in feet per sec.* V	V_m	V_b(†)	$V_{\frac{1}{2}D}$	Ratios. $\frac{V_b}{V}$	$\frac{V}{V_{\frac{1}{2}D}}$	Series C. Depth (D) in feet.	Velocities in feet per sec.* V	V_m	V_b(†)	$V_{\frac{1}{2}D}$	Ratios. $\frac{V_b}{V}$	$\frac{V}{V_{\frac{1}{2}D}}$	Series D. Depth (D) in feet.	Velocities in feet per sec.* V	V_m	V_b(†)	$V_{\frac{1}{2}D}$	Ratios. $\frac{V_b}{V}$	$V+V_{\frac{1}{2}D}$
1	8.00	1.17	1.26	0.80	1.24	0.69	0.90	9.46	1.41	1.45	1.05	1.44	0.74	0.98	9.51	1.53	1.62	1.29	1.57	0.84	0.97
2	7.17	0.57	0.59	0.50	0.56	0.88	0.98	9.37	0.93	0.96	0.83	0.95	0.89	0.98	9.51	1.53	1.64	1.33	1.56	0.87	0.98
3	7.26	0.68	0.76	0.60	0.70	0.88	0.97	9.34	0.48	0.50	0.43	0.50	0.89	0.96	9.32	1.54	.....	.....	.....	.....	.....
4	8.10	1.27	1.37	1.01	1.33	0.80	0.96	8.92	0.27	0.29	0.22	0.29	0.82	0.94	9.54	0.77	.....	.....	.....	.....	.....
5	7.54	0.84	0.87	0.64	0.85	0.76	0.99	7.67	1.44	1.54	1.12	1.52	0.78	0.95	9.54	0.77	.....	.....	.....	.....	.....
6	8.37	1.46	1.55	1.22	1.53	0.82	0.96	7.64	1.02	1.09	0.78	1.06	0.76	0.96	9.52	0.62	.....	.....	.....	.....	.....
7	7.85	1.06	1.10	0.92	1.08	0.87	0.98	7.58	0.59	.....	.....	.....	.....	.....	9.52	0.62	.....	.....	.....	.....	.....
8	7.85	1.06	1.09	0.92	1.07	0.87	0.99	7.56	0.26	0.29	0.15	0.28	0.58	0.93	7.25	1.91	2.01	1.65	1.96	0.86	0.97
9	7.85	1.06	1.10	0.92	1.07	0.87	0.99	6.01	0.52	0.58	0.37	0.57	0.71	0.91	7.25	1.91	2.01	1.61	1.98	0.84	0.96
10	7.98	1.18	1.24	0.83	1.20	0.70	0.98	6.28	1.94	2.17	1.42	2.07	0.73	0.94	7.22	1.65	1.77	1.42	1.69	0.85	0.98
11	7.73	0.98	1.01	0.79	1.00	0.81	0.98	6.40	1.28	1.41	0.94	1.37	0.73	0.94	7.22	1.65	1.72	1.44	1.70	0.87	0.97
12	7.28	0.64	0.71	0.49	0.70	0.77	0 92	6.32	0.89	0.98	0.63	0.96	0.71	0.93	7.18	0.96	1.01	0.80	0.99	0.83	0.97
13	7.48	0.97	0.89	0.65	0.88	0.83	0.90	8.48	0.48	0.54	0.40	0.53	0.79	0.91	7.18	0.96	1.03	0.76	1.00	0.80	0.96
14	7.28	0.64	0.73	0.42	0.68	0.66	0.94	8.47	1.45	1.60	1.04	1.58	0.72	0.92	7.11	.....	.....	.....	.....	.....	.....
15	7.48	0.79	0.87	0.56	0.85	0.71	0.93	8.51	0 92	0.96	0.67	0.95	0.73	0.97	5.15	0.69	0.71	0.59	0.68	0.86	0.99
16	.....	.....	.....	.....	.....	.....	.....	8.46	0.23	0.26	0.15	.....	0.65	.....	5.15	0.69	0.72	0.62	0.68	0.89	0.99
						0.795	0.958						0.747	0.944						0.851	0.974

* Correct velocities found from standard weir. † Velocity 2½ inches above the bottom.

NOTE.—V=mean velocity; V_m=maximum velocity; V_b=bottom velocity; $V_{\frac{1}{2}D}$=mid-depth velocity.

Velocity ratios in Cornell University experiment canal as found with current meters in May, November, and December, 1900.

No. of experiment.	Series A.				Series C.				Series D.			
	Velocity (v_0).	Depth (D).	Ratio $\left(\frac{v_0}{v_3}\right)$.	Ratio $\left(\frac{v_0}{v_6}\right)$.	Velocity (v_0).	Depth (D).	Ratio $\left(\frac{v_0}{v_3}\right)$.	Ratio $\left(\frac{v_0}{v_6}\right)$.	Velocity (v_0).	Depth (D).	Ratio $\left(\frac{v_0}{v_3}\right)$.	Ratio $\left(\frac{v_0}{v_6}\right)$.
	Ft. per sec.	*Feet.*			*Ft. per sec.*	*Feet.*			*Ft. per sec.*	*Feet.*		
1	1.10	8.00	1.082	1.050	1.45	9.46	1.022	1.009	1.52	9.51	1.059	1.012
2	0.45	7.17	1.062	1.036	0.97	9.37	1.029	1.017	1.48	9.51	1.071	1.002
3	0.68	7.26	1.066	0.997	0.49	9.34	1.037	1.022	.....	9.32	.....	.....
4	1.27	8.10	1.060	1.014	0.26	8.92	1.061	0.981	0.83	9.54	1.031	0.988
5	0.79	7.54	1.073	1.010	1.45	7.67	1.057	1.021	0.79	9.54	1.039	1.000
6	1.44	8.37	1.070	1.033	1.00	7.64	1.073	1.025	0.68	9.52	1.034	1.000
7	1.04	7.85	1.040	1.003	0.50	7.58	.....	.....	0.65	9.52	1.046	1.010
8	0.98	7.85	1.034	1.013	0.22	7.56	1.091	1.082	1.86	7.25	1.058	1.011
9	1.15	7.86	1.055	1.000	0.49	6.01	1.091	1.069	1.87	7.25	1.056	1.027
10	1.29	7.98	1.062	1.025	1.89	6.28	1.127	1.042	1.68	7.22	1.038	1.010
11	0.94	7.73	1.050	1.021	1.25	6.40	1.094	1.045	1.65	7.22	1.039	1.018
12	0.53	7.28	1.103	1.043	0.85	6.32	1.090	1.056	1.02	7.18	1.060	1.023
13	0.74	7.48	1.070	1.046	0.46	8.48	1.056	1.043	0.96	7.18	1.070	1.017
14	0.64	7.28	1.146	1.001	1.46	8.47	1.061	1.036	.....	7.11	.....	.....
15	0.83	7.48	1.155	1.030	0.89	8.51	1.025	1.042	0.73	5.15	1.041	1.011
16	.....	.....	.....	.....	0.20	8.46	1.139	1.030	0.67	5.15	1.045	1.015
			1.077	1.021			1.069	1.035			1.048	1.010

v_0 = velocity obtained by ordinary method.
v_3 and v_6 = velocity at three-tenths and at six-tenths depth below the surface.

MEAN VELOCITY BY INTEGRATION IN VERTICALS.

The mean velocity in the discharge section was obtained by the method of integration in the eight verticals 1, 3, 5, etc., immediately after making experiments 1, 3, 9, and 37 of series E. In the following table the velocity thus obtained is compared with that obtained by the ordinary point method in the experiment just preceding:

Comparison of mean velocity obtained by the ordinary point method and by integration in verticals in Cornell University experiment canal.

Date.	Depth.	Kind of meter.	Velocity.		$\frac{V_p - V_1}{V_p}$
			Point method (V_p).	Integration method (V_1).	
1901.	*Feet.*		*Ft. per sec.*	*Ft. per sec.*	*Per cent.*
April 1	9.08	Haskell No. 3	1.468	1.460	+0.6
April 2	6.08	do	2.208	2.225	−0.8
April 5	7.41	do	1.883	1.921	−2.0
April 11	9.26	S. Price No. 351	1.522	1.568	−3.0

It will be seen that the agreement is close, the greatest difference being 3 per cent.

RATING METERS IN STILL AND IN MOVING WATER.

The results of meter and standard-weir comparisons are given in the tables on pages 64 to 67. With a few exceptions, already mentioned, these are shown graphically in figs. 16, 17, and 18, pages 68 and 69. The straight lines 0–0′ represent in each case the weir discharge and the curved lines drawn through the plotted points repre-

sent the percentage variation of the meter discharge from the corresponding weir discharge. The meter discharge is computed from a rating table prepared from ratings in still water. If we assume that the weir discharge is correct, then these curves show the percentage difference between a rating in still water and a rating in moving water, and furnish the data for preparing a rating table for moving water from the one for still water. We have only to apply the correction to any velocity for any given number of revolutions per second, shown on the proper diagram, to obtain the velocity in moving water. This has been done, and the rating tables of the meters in still and in moving water are given in the following table. The velocity in moving water for any given number of revolutions per second is greater for all speeds of the Price meters than the velocity in still water. For the Haskell meter (a propeller instrument) the velocity is less in moving water than in still water for low velocities, and probably about the same in moving water as in still water for the higher velocities.[a] The discharges might now be computed, using the rating tables for moving water, and they would agree closely with the weir discharges. New vertical velocity curves have been found for series A, and the mean velocity ascertained from them. The shape of the new curve differs little from the old one, as the range of velocities for any curve is small. The new velocities obtained from the corrected curves are given in the second column of the table.

Rating tables of current meters in still water and in moving water in Cornell University experiment canal.

Revolutions per second.	Small Price No. 351.[b]		Large Price No. 88.[b]		Haskell No. 3.[c]		Fteley.[b]		Revolutions per second.	Haskell No. 3.[c]		Fteley.[b]	
	V	V_w	V	V_w	V	V_w	V	V_w		V	V_w	V	V_w
.....	.....	.....	.....	.....	.....	.....	.....	.....	1.10	1.30	1.28	1.18	1.07
.....	.....	.....	.....	.....	.....	.....	.....	.....	1.20	1.40	1.39	1.29	1.15
0.10	0.284	0.318	.....	.....	.....	.....	.....	.....	1.30	1.50	1.49	1.39	1.23
0.15	0.397	0.437	0.54	0.660	.....	.....	.....	.....	1.40	1.60	1.60	1.50	1.30
0.20	0.510	0.552	0.70	0.804	.....	.....	.....	.....	1.50	1.71	1.70	1.61	1.38
0.25	0.625	0.664	0.86	0.950	.....	.....	.....	.....	1.60	1.81	1.81	1.72	1.45
0.30	0.741	0.776	1.03	1.097	.....	.....	.....	.....	1.70	1.92	1.92	1.82	1.53
0.35	0.857	0.887	1.19	1.244	.....	.....	.....	.....	1.80	2.02	2.03	1.93	1.60
0.40	0.972	0.998	1.35	1.392	.....	.....	.....	.....	1.90	2.13	2.14	2.04	1.67
0.45	1.088	1.109	1.52	1.550	.....	.....	.....	.....	2.00	2.23	2.24	2.14	1.74
0.50	1.204	1.220	1.68	1.709	0.70	0.647	0.536	0.552	.....	.....	.....	.....	.....
0.55	1.319	1.332	1.84	1.874	0.75	0.698	0.589	0.598	.....	.....	.....	.....	.....
0.60	1.435	1.447	2.01	2.042	0.80	0.751	0.643	0.644	.....	.....	.....	.....	.....
0.65	1.550	1.562	2.17	2.207	0.85	0.803	0.697	0.690	.....	.....	.....	.....	.....
0.70	1.660	1.677	2.34	2.373	0.90	0.855	0.750	0.735	.....	.....	.....	.....	.....
0.75	1.782	1.796	2.50	2.538	0.95	0.907	0.804	0.779	.....	.....	.....	.....	.....
0.80	1.897	1.915	2.66	2.702	1.00	0.960	0.858	0.822	.....	.....	.....	.....	.....
0.85	2.013	2.033	2.83	2.868	1.05	1.014	0.911	0.864	.....	.....	.....	.....	.....
0.90	2.129	2.150	2.99	3.034	1.10	1.068	0.965	0.905	.....	.....	.....	.....	.....
0.95	2.244	2.266	3.15	3.199	1.15	1.121	1.018	0.946	.....	.....	.....	.....	.....
1.00	2.36	2.38	3.32	3.366	1.20	1.174	1.072	0.987	.....	.....	.....	.....	.....

[a] Recent experiments with a Fteley meter do not verify this statement.
[b] Meter held with rigid rod.
[c] Meter held with cable.

NOTE.—V=velocity, in feet per second, from still-water rating; V_w=velocity, in feet per second, from moving-water rating.

A reason for the percentage increase in the variation of the meter discharge from the weir discharge as the velocity decreases is to be found in the rating table from which the velocities are computed. The experiment of November 1 shows that the small Price meter will measure a velocity of 0.23 foot per second, as the mean velocity found from the weir is 0.229 foot per second and the meter wheel revolved with regularity at all points where it was held. The observations in the rating do not extend to this velocity, however, and do not warrant the preparation of a rating table giving velocities of less than 0.5 foot per second.

In the three ratings of small Price meter No. 351 on May 9, 1901, shown in fig. 29, page 89, there are only four observations for velocities less than 0.5 foot per second and none below 0.45 foot per second. The extension of the table to velocities less than 0.5 foot per second is probably made on the assumption that this part of the rating curve is a straight line. That this is very far from the truth can be seen from an inspection of the three curves of fig. 29. Another reason is that discharge shown by the Cornell University standard weir is probably from 1 to 3 per cent too large for low heads on the weir. Recent experiments seem to indicate this fact. These two causes, however, account for only a comparatively small part of the difference between current-meter and weir discharge at low velocities which the experiments of series A and C, and others made since the writing of the body of this paper, indicate. The failure of the meter to indicate as high a velocity when held in a very slow-moving current, as when the meter is dragged through still water in the direction of the current, is probably due to the stream lines becoming more and more oblique to the axis of the canal as the velocity decreases, and consequently their impact on the meter being less than when they moved more nearly in the direction of the axis of the canal.

ERROR IN USING AVERAGE OF BOTTOM AND SURFACE VELOCITIES FOR MEAN VELOCITY.

The following table gives the mean velocity and the average of the velocities 0.5 foot above the bottom and 0.5 foot below the surface for the experiments of series A, C, and D; also the error, in per cent, made by using the average of surface and bottom velocities instead of the mean velocity. It is seen that in all these experiments except two the mean velocity is greater than the half sum of the surface and bottom velocities, the difference varying from − 2.2 per cent to + 30.6 per cent.

Table showing relation between mean velocity and average of surface and bottom velocities as found from Cornell University standard weir and from current meters in Cornell experiment canal.

No. of experiment.	Series A.			Series C.			Series D.		
	V	V'	$\frac{V-V'}{V}$	V	V'	$\frac{V-V'}{V}$	V	V'	$\frac{V-V'}{V}$
	Feet per second.	*Feet per second.*	*Per cent.*	*Feet per second.*	*Feet per second.*	*Per cent.*	*Feet per second.*	*Feet per second.*	*Per cent.*
1	1.164	0.987	+15.3	1.409	1.412	− 0.2	1.528	1.436	+6.2
2	0.573	0.416	+27.5	0.932	0.954	− 0.2	1.528	1.436	+6.2
3	.....	.....	.....	0.477	0.468	+ 0.2	.....	.....	.....
4	1.268	1.190	+ 6.1	0.265	0.231	+12.8	.....	.....	.....
5	0.841	0.749	+10.9	1.444	1.364	+ 5.6	.....	.....	.....
6	1.462	1.384	+ 5.4	1.018	0.940	+ 7.7	.....	.....	.....
7	1.056	0.965	+ 8.6	0.502	.....	.....	.....	.....	.....
8	1.056	0.946	+10.4	0.255	0.177	+30.6	1.905	1.807	+5.2
9	.....	.....	.....	0.515	0.435	+15.5	1.905	1.779	+6.6
10	.....	.....	.....	1.914	1.730	+ 9.6	1.649	1.613	+2.2
11	0.980	0.887	+ 9.5	1.283	1.129	+12.0	1.649	1.590	+3.6
12	0.643	0.476	+25.9	0.893	0.759	+15.0	0.955	0.973	−1.9
13	0.788	0.687	+12.7	0.478	0.422	+11.8	0.955	0.897	+6.1
14	.....	.....	.....	1.454	1.311	+ 9.8	.....	.....	.....
15	.....	.....	.....	0.915	0.784	+14.3	0.689	0.704	−2.2
16	.....	.....	.....	0.229	0.179	+21.8	0.689	0.659	+4.3

V = mean velocity found from standard weir.

V' = mean of velocities 0.5 foot above bottom and 0.5 foot below surface, as found by meters, uncorrected.

From the foregoing table, and from the table on page 79, in which is given the ratio of bottom velocity to mean velocity, it appears that bottom velocity is not a desirable quantity to use in computing discharge, for it varies between too wide limits. In a stream with a stony or gravelly bottom the limits must be considerably greater than in the Cornell canal with its smooth bottom. Observations at mid depth or at six-tenths depth give better results.

COMPARISON OF RESULTS BY THREE METHODS OF OPERATING METER.

Three methods of operating meters have been used in these experiments, viz, the ordinary method, the six-tenths-depth, and the integration. A detailed account of the manner of operating the meter by each of these methods has been given on pages 62 to 63. The time required to make a discharge measurement was from thirty to sixty minutes with the ordinary method, from twenty to thirty minutes with the six-tenths-depth, and from five to ten minutes with the integration.

The results by the ordinary method in series A to D (fig. 16, p. 68) give for each meter a well-defined line which agrees with the weir line (0–0′) within about 2 per cent for velocities greater than 1.5 feet per second, the meter discharge being less than the corresponding weir discharge.

The agreement with the weir discharge is closer in series E than in series A to D, being −0.03 per cent for the Haskell meter, −1.13 per cent for Price meter No. 363, and −1.88 per cent for Price meter No. 351. The results by the six-tenths-depth method do not give as well

defined a line (fig. 17) for each meter as do those by the ordinary method, the meter discharge being from 1 to 6 per cent greater than the corresponding weir discharge, and the mean being 3.5 per cent for small Price meter No. 363. If the observations with the latter meter had been taken at sixty-four-hundredths depth instead of at six-tenths depth the line representing the mean would coincide with the weir line 0–0′, and the greatest percentage variations from the mean would be −2.5 per cent and +2.5 per cent.

The results by the integration method do not give a well-defined line. The meter discharge is from 1 per cent to 9 per cent greater than the weir discharge for velocities greater than 0.5 foot per second in the experiments of series C and D, and from 0 to 5 per cent less than the weir discharge for the experiments of series A. The following table gives the true velocity as found from the weir and the velocity found by the integration method for different speeds of the meter, also the ratio of difference between these velocities and the true velocity, expressed in per cent:

Table showing effect of variation of speed of meter in integration method.

No. of experiment.	Date.	Depth.	True velocity by weir (V) per second.	Speed of meter per second.	Velocity of water by meter (V_1) per second.	$\frac{V-V_1}{V}$	Kind of meter.
	1900.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Per cent.*	(a)
1	May 8	8.10	1.268	0.101	1.268	0.00	S. P. 351.
2	do	8.10	1.268	0.152	1.235	+ 2.60	Do.
3	do	8.10	1.268	0.270	1.200	+ 5.35	Do.
4	do	7.54	0.841	0.079	0.834	+ 0.09	Fteley.
5	do	7.54	0.841	0.055	0.842	− 0.01	Do.
6	May 9	7.85	1.056	0.056	1.028	+ 2.65	S. P. 351.
7	do	7.85	1.056	0.043	1.008	+ 4.54	L. P. 88.
8	May 15	7.73	0.980	0.032	0.978	+ 0.02	S. P. 351.
9	October 24	9.46	1.409	0.118	1.429	− 1.42	S. P. 363.
10	do	9.37	0.932	0.142	0.982	− 5.36	Do.
11	do	9.34	0.477	0.164	0.485	− 1.68	Do.
12	do	8.92	0.265	0.107	0.308	−16.23	Do.
13	October 26	7.67	1.444	0.137	1.519	− 5.20	Do.
14	do	7.64	1.018	0.135	1.079	− 5.99	Do.
15	October 27	7.58	0.502	0.143	0.522	− 3.99	Do.
16	do	7.56	0.255	0.128	0.312	−22.35	Do.
17	do	6.01	0.515	0.142	0.555	− 7.77	Do.
18	do	6.28	1.940	0.180	2.030	− 4.64	Do.
19	do	6.40	1.283	0.154	1.338	− 4.29	Do.
20	do	6.32	0.893	0.188	0.920	− 3.02	Do.
21	October 29	8.48	0.478	0.151	0.492	− 2.93	Do.
22	October 31	8.47	1.454	0.298	1.552	− 6.74	Do.
23	do	8.51	0.915	0.258	1.002	− 9.51	Do.
24	November 1	8.46	0.229	0.185	0.319	−39.30	Do.
25	December 6	9.51	1.528	0.253	1.540	− 0.78	Do.
26	do	9.51	1.528	0.284	1.572	− 2.87	Hask. 3.
27	December 7	9.32	1.535	0.243	1.576	− 2.66	Do.
28	December 8	7.25	1.905	0.252	1.962	− 2.99	Do.
29	do	7.22	1.649	0.295	1.748	− 6.00	Do.
30	do	7.18	0.955	0.254	1.039	− 8.79	Do.
31	do	5.15	0.689	0.179	0.752	− 9.14	Do.

(a) S. P. = small Price; L. P. = large Price; Hask. = Haskell. Figures given are the numbers of the meters.

Table showing effect of speed of meter on observed velocity as found by the integration method in experiments of table on page 84.

Experiments Nos. 9 to 25, omitting Nos. 12, 16, and 24.						Experiments Nos. 1 to 8.			
Speed of meter 0.10 to 0.14.	$\frac{V-V_1}{V}$	Speed of meter 0.14 to 0.18.	$\frac{V-V_1}{V}$	Speed of meter 0.18 to 0.30.	$\frac{V-V_1}{V}$	Speed of meter 0.05 to 0.15.	$\frac{V-V_1}{V}$	Speed of meter 0.15 to 0.30.	$\frac{V-V_1}{V}$
Feet per second.	*Per cent.*	*Feet per second.*	*Per cent.*	*Feet per second.*	*Per cent.*	*Feet per second.*	*Per cent.*	*Feet per second.*	*Per cent.*
0.118	−1.42	0.142	−5.36	0.180	−4.64	0.056	+2.65	0.152	+2.60
0.137	−5.20	0.164	−1.68	0.188	−3.02	0.043	+4.54	0.270	+5.35
0.135	−5.99	0.143	−3.99	0.293	−6.74	0.032	+0.02	----------	----------
0.130	−4.20	0.142	−7.77	0.258	−9.51	0.101	+0.00	----------	----------
----------	----------	0.154	−4.29	0.253	−0.78	0.079	+0.09	----------	----------
----------	----------	0.151	−2.93	0.234	−4.94	0.055	−0.01	----------	----------
----------	----------	0.159	−6.33	----------	----------	0.061	+1.22	0.211	+3.97

This ratio is positive for all the experiments of series A and is negative for those of C and D. This difference of sign is due to two causes: (1) The meter was moved faster in the experiments of C and D than in those of series A; and (2) it was moved through only 14 feet of the width in series C and D and through nearly 15.5 feet of the width in series A, and the additional 1.5 feet of width had a small velocity. It is seen from the above table that for low velocities the error in velocity increases as the speed of the meter increases. The table on page 84 shows this effect for velocities from 0.5 foot to 2 feet per second.

COMPARISON OF RESULTS OBTAINED IN 1900 WITH THOSE OBTAINED IN 1901.

Examining the plotted results in figs. 16 (page 68) and 18 (page 69), it is seen that the meter discharge, compared with the corresponding weir discharge, is somewhat larger for the work of 1901 than for that of 1900 for velocities greater than 1.4 feet per second. This can not be due to change in rating of the meters, for an increase in the friction in a meter would reduce the observed velocity and make the meter discharge too small. There was considerably more seepage into the canal when the experiments of series E (1901) were made than at the time those of A, B, C, and D (1900) were made. There was also quite a little surface water entering the canal between the weir and the meter section in the experiments of series E. It is hardly possible, however, that this inflow between the weir and the meter section could amount to 2 per cent of the canal discharge. It must be borne in mind in this connection that the discharges obtained in 1900 for velocities greater than 1.4 feet were in shallow water, and therefore are not so reliable as those obtained in series E.

EFFECT OF METHOD OF HOLDING METER IN WATER.

In some of the experiments the meter was suspended from a cable; in others it was held in the water with a rigid rod. In the latter cases its axis was free to move about a horizontal axis; in the former cases

it was free to move about a vertical as well as a horizontal axis. When used with a cable a sinker is necessary, which, being attached to the under side of the meter, keeps the axis of the revolving wheel farther from the bottom than is desirable in some cases. It is also difficult to keep the meter in any desired place when held with a cable, and it usually changes its position considerably in a swift current. It was in order to measure the velocity close to the bottom and keep the meter at a desired place during the observation that in many of the experiments the meter was held with a rod. In ordinary river gaging, however, the Price and Haskell meters are held with cables and the meters are rated in still water suspended from a car and cable. The question then arose: "Is the rating table for a meter used suspended from a cable applicable to the same meter held with a rigid rod?"

On December 30, 1900, Mr. E. G. Paul made two ratings of small Price meter No. 351 in still water, one with the meter held with a rigid rod and the other with the meter held with a cable and a 5-pound lead sinker. In the following tables (pp. 87 and 88) are given the observations and computations of these ratings. The second column ("time in seconds") gives the average time required for the car to which the meter was attached to move over a run of 100 feet, and again over the same course in the opposite direction; the third column gives the number of revolutions observed in this average time; the seventh column gives for each of these cases the difference between the observed velocity and the velocity computed from the old rating table of April 23, 1900, for the same meter held with a cable. The tenth column of the first table (p. 87) gives the difference between the observed velocities and those computed from the new rating table, which is based on meter rated in still water and held by a rigid rod. The portion of this new rating table which was used in reducing the Cornell experiments is given on page 81. By comparing the corresponding quantities in the seventh and tenth columns of this table it will be seen how much more closely the values in the new rating table fit the observations than do those of the old one. The tenth column shows also how much the relation between the revolutions per second of this meter and the velocity as shown by these observations differs from the "most probable" straight line, $y=0.047+2.313x$, y being velocity in feet per second and x revolutions of meter wheel per second. From the seventh column of the table on page 87 it is seen that the observed velocities are larger than the computed velocities, indicating more friction in the meter on December 30, 1900, than on April 23, 1900.

The "most probable" linear relation between x and y for this case of the meter held with a cable was found to be $y=0.067+2.321x$. The differences in the tenth column show that this line does not fit the observations. It crosses the curve given by the observations twice as

y increases from 1 to 8 feet per second. The rating table was prepared by using this line as a basis, applying corrections as indicated by the corresponding difference of the tenth column, and also that the rating table will difference smoothly. The numbers in column 12 show how closely the observed velocities agree with those computed from the new rating table with the meter held with a cable.

It should be noted that the smallest observed velocity is about 0.5 foot per second in one case and 0.35 foot in the other case.

Observations and computations of a rating of small Price meter No. 351 held by rigid rod, made at Chevy Chase, Md., December 30, 1900.

1.	2 and 3.		4.	5.	6.	7.	8.	9.	10.	11.
No. of observation.	Length of run, 100 feet.		Revolutions per second (x).	Observed velocity (y).	Computed velocity (y^1).[a]	Difference ($y-y^1$).	x^2	xy	Residual (v).	v^2
	Time.	Revolutions of meter.								
	Seconds.			*Feet per second.*	*Feet per second.*	*Ft. per second.*				
1	9.25	43.00	4.648	10.811	10.815	−.004	21.604	50.245	+.059	.003481
2	10.5	42.50	[b]4.048	[b]9.524	9.405	+.119				
3	16.0	43.00	2.688	6.250	6.231	+.019	7.225	16.800	−.014	.000196
4	22.5	43.00	1.911	4.444	4.414	+.030	3.652	8.493	−.022	.000484
5	35.0	42.25	1.207	2.857	2.797	+.060	1.457	3.448	+.018	.000324
6	45.0	42.00	0.933	2.222	2.183	+.039	0.870	2.073	+.017	.000289
7	53.0	42.00	0.794	1.887	1.867	+.020	0.630	1.498	+.003	.000009
8	54.5	42.00	0.774	1.835	1.823	+.012	0.599	1.420	−.003	.000009
9	68.0	41.75	0.614	1.471	1.461	+.010	0.377	0.903	+.004	.000016
10	85.5	41.75	0.488	1.170	1.174	−.004	0.238	0.571	−.006	.000036
11	106.5	41.00	0.385	0.939	0.944	−.005	0.148	0.362	+.001	.000001
12	113.0	41.00	0.363	0.885	0.891	−.006	0.132	0.321	−.002	.000004
13	154.0	40.50	0.263	0.649	0.669	−.020	0.069	0.171	−.006	.000036
14	197.0	39.50	0.201	0.508	0.522	−.014	0.040	0.102	−.004	.000016
15	220.0	39.00	0.177	0.455	0.569	−.014	0.031	0.081	−.001	.000001
16	293.0	36.90	0.126	0.341	0.351	−.010	0.016	0.043	−.003	.000009
			15.572	36.724			37.088	86.531		.004911

[a] Computed from rating table prepared from rating of April 23, 1900.

[b] Omitted in computing Σx and Σy.

NOTE.—Observation equation, $y-a-bx=v$; normal equations, $a\Sigma x+b\Sigma x^2=\Sigma xy$, $na+b\Sigma x=\Sigma y$. For these observations these become $15.572\,a+37.088\,b=86.531$, $15\,a+15.572\,b=36.724$. The solution of these gives $b=2.313$ and $a=.047$. The mean error of a single observation is $\sqrt{\frac{\Sigma v^2}{n-1}}=.019$. The probable error of result is $6.745\sqrt{\frac{\Sigma v^2}{n(n-1)}}=.003$.

Observations and computations of a rating of small Price meter No. 351 held by cable, made at Chevy Chase, Md., December 30, 1900.

1.	2 and 3.		4.	5.	6.	7.	8.	9.	10.	11.	12.
	Length of run, 100 feet.										
No. of observation.	Time.	Revolutions of meter.	Revolutions per second (x).	Observed velocity (y).	Computed velocity (y').[a]	Difference ($y-y'$).	x^2	xy	Residual (v).	Computed velocity (y'').[b]	Difference ($y-y''$).
	Seconds.			*Ft. per second.*	*Ft. per second.*	*Ft. per second.*				*Ft. per second.*	
1	10.5	42.00	4.000	9.524	9.300	+.224					
2	12.5	42.50	3.400	8.000	7.900	+.100	11.560	27.200	+.042	7.98	+.02
3	16.5	42.50	2.576	6.061	5.967	+.094	6.636	15.613	+.015	6.04	+.021
4	21.5	42.75	1.990	4.651	4.588	+.063	3.960	9.256	−.034	4.68	−.029
5	26.0	42.50	1.635	3.846	3.767	+.079	2.673	6.288	−.015	3.837	+.009
6	29.0	42.50	1.465	3.448	3.383	+.065	2.146	5.051	−.020	3.443	+.005
7	31.0	42.25	1.363	3.226	3.151	+.075	1.858	4.397	−.004	3.290	+.017
8	41.0	42.50	1.037	2.439	2.411	+.028	1.075	2.529	−.034	2.451	−.012
9	50.0	42.50	0.850	2.000	1.990	+.010	0.723	1.700	−.039	2.024	−.024
10	61.0	42.00	0.688	1.639	1.624	+.015	0.473	1.128	−.024	1.655	−.016
11	70.0	42.00	0.600	1.429	1.430	−.001	0.360	0.857	.030	1.454	−.025
12	80.5	41.25	0.512	1.242	1.226	+.016	0.262	0.636	−.013	1.256	−.014
13	90.5	40.00	0.442	1.105	1.072	+.033	0.195	0.488	+.012	1.098	+.007
14	105.5	39.00	0.370	0.949	0.908	+.041	0.137	0.351	+.024	0.938	+.011
15	125.0	38.00	0.304	0.800	0.759	+.041	0.092	0.243	+.028	0.790	+.010
16	140.0	37.00	0.264	0.714	0.671	+.043	0.070	0.189	+.035	0.697	+.017
17	171.0	36.00	0.215	0.585	0.556	+.029	0.046	0.126	+.019	0.585	−.000
18	184.0	36.00	0.196	0.543	0.507	+.036	0.038	0.106	+.022	0.541	+.002
19	211.0	35.75	0.169	0.474	0.452	+.022	0.029	0.080	+.015	0.479	−.005
			18.076	43.151			32.334	76.239			

[a] Computed from rating of April 23, 1900.

[b] Computed from rating of December 30, 1900.

NOTE.—Most probable straight line given by these observations, $y=.067+2.321x$.

The following table shows the percentage difference of velocity for each 0.05 revolution for these two ways of holding the meter. It is seen that a given number of revolutions per second of this meter indicates a higher velocity when it is held with a cable than when it is held with a rigid rod, and that this percentage difference decreases as the velocity increases. In other words, in a given velocity the meter will revolve faster when held with a rigid rod than when held with a cable. It must be remembered that the values given in this table for velocities less than about 0.5 foot per second are only approximate, since the observations do not extend below 0.35 foot per second. We may say that if the rating table for this meter held with a cable be used to reduce observations made with the meter held with a rigid rod, the results will be in error from 1.3 per cent to 8.5 per cent for velocities from 1.5 feet to 0.5 foot per second.

Table showing percentage difference in velocity as shown by small Price meter No. 351 when rated in still water on a rigid rod and on a cable.

Speed of meter.	V_r	V_c	$\frac{V_r - V_c}{V_r}$	Speed of meter.	V_r	V_c	$\frac{V_r - V_c}{V_r}$
R. per sec.	*F. per sec.*	*F. per sec.*	*Per cent.*	*R. per sec.*	*F. per sec.*	*F. per sec.*	*Per cent.*
0.15	0.397	0.433	9.1	0.60	1.435	1.455	1.4
0.20	0.510	0.550	7.8	0.65	1.550	1.568	1.2
0.25	0.625	0.666	6.6	0.70	1.666	1.682	1.0
0.30	0.741	0.781	5.4	0.75	1.782	1.796	0.8
0.35	0.857	0.894	4.3	0.80	1.897	1.910	0.7
0.40	0.972	1.006	3.5	0.85	2.013	2.024	0.5
0.45	1.088	1.118	2.8	0.90	2.129	2.138	0.4
0.50	1.204	1.230	2.2	0.95	2.244	2.252	0.4
0.55	1.319	1.342	1.7	1.00	2.36	2.37	0.3

V_r = velocity with meter rated on a rigid rod.
V_c = velocity with meter rated on a cable.

Small Price meter No. 351 was again rated three times on May 9, 1901. It was held (1) with a cable, using an 18-pound sinker; (2) with a rod, the meter being free to tip; and (3) with a rod and the meter not free to tip. Space will not permit the insertion of the observed data or the computations, but the results are plotted in fig. 29, using R= revolutions per second as abscissæ and $K=\frac{V}{R}$=ratio of velocity to revolutions as ordinates. It is seen that these rating observations give a separate curve for each of these cases. The value of K for any value of R for one curve is very different from that for the other curves for velocities less than about 3 feet per second. For example, for R=0.3, K=2.755 for case 1 (curve AE), 2.585 for case 2 (curve BE), and 2.485 for case 3 (curve DF). The coefficient is largest when the meter has the most freedom of motion and least when it has no freedom of motion. As the velocity for a given number of revolutions varies directly with K, the velocity decreases as the freedom to tip about a horizontal axis and to swing around a vertical axis decreases. Or, stated in the other way, in a current of a given velocity the revolutions increase as the freedom of motion decreases. Each of these cases therefore requires a separate rating table.

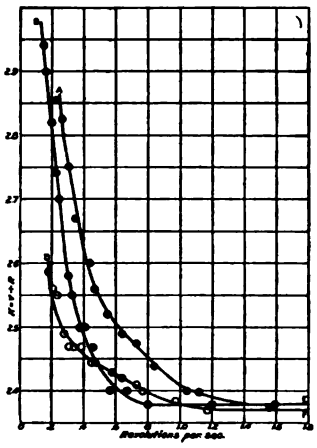

FIG. 29.—Curves showing relation between revolutions of meter and ratio between velocity of water and revolutions of meter from three ratings of small Price meter No. 351 at Chevy Chase, Md., May 9, 1901. Crossed circles are for observations with meter held with cable, an 18-pound sinker being used. Heavy black dots are for observations with meter held with rod and free to tip. Open circles are for observations with meter held with rod and not free to tip.

SURFACE VELOCITY EXPERIMENTS WITH FLOAT RODS AND WITH CURRENT METERS.

It was noticed during the weir and current-meter comparisons that the shape of the vertical velocity curve near the surface obtained with

a small Price meter was quite different under certain conditions from that obtained with the Haskell meter under the same conditions. This peculiarity can be seen in the simultaneously obtained curves of fig. 30. The Haskell meter indicates a higher surface velocity than the Price meter. By surface velocity obtained with a meter is meant that obtained when the revolving part of the meter is entirely under water all of the time and yet as close to the surface as possible. For the three meters used in these surface velocity observations the distance of the center below the surface was as follows: Small Price meter No. 351, from 2.5 to 3 inches; Fteley No. 107, from 3 to 3.5 inches; Haskell No. 3, from 4 to 4.5 inches.

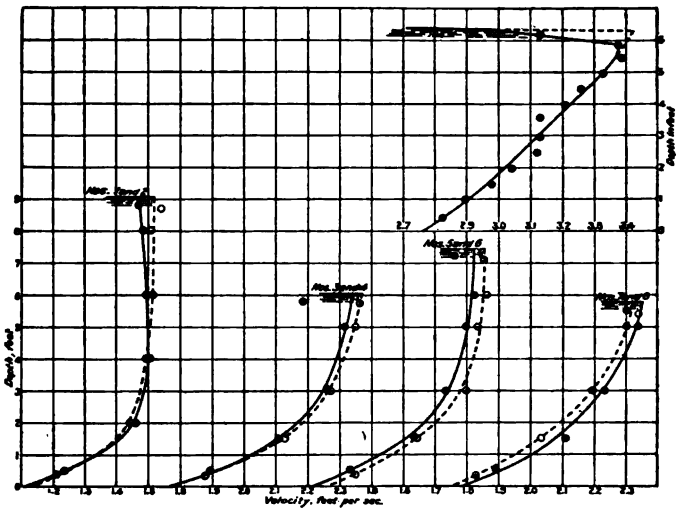

FIG. 30.—Vertical velocity curves from simultaneous experiments of series E with small Price meter No. 363 and with Haskell meter No. 3. Large black dots are for Price meter, open circles for Haskell meter.

In order to investigate this matter further the surface velocity of a part of the canal was measured simultaneously with floats and with two current meters. The floats used were 6-inch cubes of wood loaded with lead so as to have an immersion of 5¼ inches. Surface floats of wood 6 inches by 6 inches by 1 inch thick were also used. These were started near the center of the canal 18 feet above the upper wire and timed over a run of 60 feet. Any that passed the lower wire within 2 feet of either side were not used in computing velocity. The meters were held 10 feet below the lower wire, the Haskell at 5 and 7 feet from the south side of the canal, the Price at 9 and 11 feet from the south side, and the revolutions were counted for periods of forty seconds. The results of the experiments are given in the following table:

Comparison of surface velocity measured with float rods and with current meters.

Small Price meter No. 351.				Haskell meter No. 3.			
Number of float observations.	Velocity with floats.	Number of 40-second periods.	Velocity with meter.	Number of float observations.	Velocity with floats.	Number of 40-second periods.	Velocity with meter.
	Feet per second.		*Feet per second.*		*Feet per second.*		*Feet per second.*
11	3.122	10	2.794	13	3.083	13	3.171
12	3.076	12	2.806	12	3.144	12	3.187
13	3.030	13	2.818	10	3.135	10	3.165
36	3.076	35	2.806	35	3.121	35	3.174

During the foregoing observations the depth of water in canal was 6.04 feet, its mean velocity 2.8 feet, and the discharge 275.3 cubic feet per second. The float velocity that is compared with the Price meter velocity is obtained from the floats passing the lower wire from 2 to 8 feet from the south side of canal; that which is compared with the Haskell meter velocity is found from the floats passing the lower wire from 8 to 14 feet from the south side of canal. It is seen that in each experiment the float velocity is greater than that of the Price meter and less than that of the Haskell meter. The mean float velocity for the three experiments is 8.8 per cent greater than the velocity with the Price meter and 1.7 per cent less than that with the Haskell meter.

It was thought that possibly this failure of the small Price meter to give correct surface velocity indications was due to wave motion of the meter. Another experiment was therefore made with the floats and with the meter held with a rod and not free to tip. Fteley electric meter No. 107 was also used in place of the Haskell meter. The floats were started at many points in the width of the canal and were timed over a run of 50 feet. Those that came within 2 feet of either bank were not used in computing the velocity. The meters were held 24 feet below the lower wire at points from 0 to 7 feet from the center, and the revolutions were counted for 50-second periods.

The mean surface velocity shown by the small Price meter from thirty-two 50-second periods is 1.967 feet, and the corresponding float velocity obtained from ten floats passing from 2 to 8 feet from the south side of canal is 2.146 feet. The corresponding surface velocity shown by the Fteley meter is 2.074 feet, and by the floats from 8 to 14 feet from the south side of canal, 2.137 feet. The float velocity is 8.3 per cent greater than the Price meter velocity and 2.95 per cent greater than the Fteley meter velocity. The difference between the float and the Price meter velocities is about the same as in the previous experiments.

During this experiment the Price meter was held 3.5 feet from the south side of canal, with its center $2\frac{3}{4}$ inches below the surface for seven 50-second periods, and again with its center 4.5 inches below

the surface for about the same length of time. The mean velocity at 2¾ inches depth was 1.884 feet, and at 4.5 inches depth it was 2.035 feet. The float velocity at this point was 2.137 feet. The indicated velocity increased 7.4 per cent as the meter was lowered 1¾ inches. The float work in this experiment is not very satisfactory.

On May 20 vertical velocity-curve data were taken with small Price meter No. 351 and with Haskell meter No. 3 for different mean velocities, with a view to determining the magnitude of this error at different velocities and depths below the surface. The Haskell meter was held with a cable 1 foot south of the center of the canal and 244 feet from the weir; the Price meter was held with a cable 1 foot north of the center of canal. The following data were obtained:

Velocities near the surface of Cornell University experiment canal as found with small Price meter No. 351 and with Haskell meter No. 3.

Number of run.	Small Price meter No. 351.[a]				Haskell meter No. 3.[b]		
	Depth below surface, in inches.				Depth below surface, in inches.		
	2.5	4.5	6.5	8.5	4.5	6.5	8.5
Second	0.482	0.490	0.482	.....	0	0	0
Third	0.556	0.595	0.575	.....	0.592	0.615	0.602
Fourth	0.996	0.958	0.958	0.942	1.015	1.032	1.010
Fifth	1.297	1.281	1.320	1.299	1.348	1.325	.....
Sixth	1.480	1.457	1.399	1.484	1.450	1.392	1.412
Seventh	1.611	1.556	1.533	.....	1.552	1.572	.....

[a] Meter held with cable 1 foot north of canal center and 244 feet from weir.
[b] Meter held with cable 1 foot south of canal center and 244 feet from weir.

Each run lasted about half an hour, during which time the mean velocity remained constant. These results indicate that for velocities less than 1.5 feet the difference between the velocities indicated by these meters is small from the surface to a depth of 8.5 inches.

In the upper right-hand corner of fig. 30 is a vertical velocity curve prepared from thirty-five 50-second observations taken in forty minutes 7 feet from the south side of the canal, at a station 220 feet from the weir, with small Price meter No. 351. It shows a decrease of 8.5 per cent in the velocity 2¾ inches below the surface.

From these float and current-meter surface velocity experiments we conclude that a small Price meter will not measure velocity correctly when its center is within 0.5 foot of the surface, if the velocity be greater than 1.5 feet per second, and that this error increases from 0 at about 0.5 foot below the surface to 8 or 9 per cent at 2.5 inches below the surface.

APPLICATION OF RESULTS TO ORDINARY RIVER GAGING.

It has been shown that the discharge of the Cornell University canal can be measured with a small Price current meter by the ordinary point method with an error of not more than 1 per cent under favorable conditions. This degree of accuracy, however, can seldom

be attained in ordinary river gaging, as the conditions are not so favorable for accurate work. The bed of the Cornell canal is hard, smooth, and regular in shape; the bed of a river is frequently of soft material, into which the meter will settle, or is gravelly, stony, and irregular in shape. There are no shallow parts in the canal, the depth and velocity of which it is difficult to measure with accuracy, but frequently there are one or more of these in a river discharge section. There is a good measurable velocity in all parts of the canal for all depths, while in a river there are frequently parts in which the velocity is too small for accurate measurement. The change in velocity from one point to another in a discharge section is frequently greater in a river than in the canal, on account of obstructions. Fluctuations of the surface elevation are also larger in a river than in the canal. On these accounts it is to be expected that ordinary river discharge measurements may be several per cent less accurate than those of this canal.

In river gaging work, however, it is not alone accurate discharge measurements that are required, but it is the accurate measurement of the volume passing the gaging station each day and each month. The accuracy of daily and monthly flow of a stream depends on the accuracy of the discharge curve, or the relation between the total discharge and the river stage, and on the accuracy of measurement of the fluctuation of river stage. The latter is quite as important as the former, and improvement in it should keep pace with improvements in the former.

ACCURACY OF RESULTS.

The discharge of the Cornell University standard weir is computed from Bazin's formula. It is not possible, however, to measure the head on the weir in exactly the same way that Bazin measured the head on his weir, so that this formula is not strictly applicable to this weir. From experiments made at the Cornell hydraulic laboratory, however, Prof. G. S. Williams believes that the actual discharge of the Cornell weir will not differ from that computed by Bazin's formula by more than 1 per cent for heads up to 1.5 feet, nor more than 3 per cent for heads up to 2.5 feet.

The results given in the tables have been obtained with five current meters operated in three ways by several observers. In several of the experiments simultaneous measurements were made with two meters, so that we have several checks on the work. We have not carried any of the computations beyond the third decimal place, believing that the length of a meter observation, the method of obtaining fractional parts of a revolution of the meter wheel, the uncertainty in the exact location of the vertical velocity curve, and the pulsations in the water do not warrant even this degree of accuracy. In closely studying the results some little inaccuracies will be found, as all the results are not obtained in exactly the same way; but they are believed to be substantially correct.

In comparing the results of these experiments with results obtained by other experimenters it must be remembered that we have used smaller velocities in many of our experiments than were used by them. In Fteley and Stearns's comparisons (p. 57) the smallest mean velocity is 1.7 feet, in Henry's (p. 50) the smallest is 3 feet, in Bazin's (p. 43) the smallest is 1.25 feet, in Francis's (p. 53) it is 0.5 foot, and in Marr's (p. 48) 2.4 feet. For these and higher velocities our meter results by the ordinary method agree closely with those given by the weir. We are unable to find any comparisons by other experimenters for velocities less than 1 foot per second, except a few by Francis with rods and those at Cornell with rods (p. 51). The large disagreement between meter and weir is for the low velocities, a field into which apparently few experimenters have entered.

CONCLUSIONS.

The conclusions to be drawn from these experiments may be briefly summarized as follows:

(1) Discharge measured with current meter by the ordinary (point) method agrees with that given by the Cornell standard weir within 2 per cent for velocities above 1.5 feet per second. (See tables on pages 64 to 67 and 70.)

(2) For velocities less than 1.5 feet per second the discharge found with the Price meters is less than the corresponding weir discharge, and the difference increases rapidly as the velocity decreases. (See tables on pages 64 to 67.)

(3) For velocities less than about 1.5 feet per second the discharge found with the Haskell meter is greater than that of the weir, and the difference increases as the velocity decreases. This difference is 6 per cent for a velocity of 0.75 foot per second. (See fig. 16.)

(4) The discharge of the Cornell canal can be measured with a small Price meter, ordinary point method, with an error of not more than 1 per cent under favorable conditions, a velocity observation lasting fifty seconds being taken in each 2.3 square feet of discharge area.

(5) When the most accurate results are desired the meter should be held with a rod and not given freedom to tip.

(6) Velocities of 1.5 feet per second and upward obtained with a small Price meter when its center is closer to the surface than 0.5 foot are too small by from 0 to 9 per cent. This error, however, decreases from maximum at the surface to 0 at about 0.5 foot depth.

(7) The small Price meter will measure velocities of 1 foot per second and less more accurately than either the large Price meter or the Haskell meter. It appears from these experiments that the smallest velocity that these meters will measure with a fair degree of accuracy is 0.5 foot for the large Price meter and the Haskell meter and 0.22 foot for the small Price meter. (See fig. 16.)

(8) The small Price meter should be frequently rated, and it should be used with much care if accurate results are required.

(9) The six-tenths-depth method gives discharge from 2 to 6 per cent in excess of that by the weir, depending on the ratio of width to depth. (See fig. 17.)

(10) The integration method as a rule gives results in excess of those given by the weir, the difference increasing with the speed of the meter and decreasing as the velocity increases. (See fig. 17 and tables on pages 84 and 85.) By using special care in moving the meter at a slow speed and a uniform rate it may be possible to obtain better results by this method than those shown by these experiments. A device like Harlacher's (page 36) for giving the meter a uniform motion will increase the accuracy somewhat. We do not believe, however, that the little saving of time of this method over that by the mid-depth or the six-tenths-depth will warrant the use of any such device. The method is useful only as a rough check on one of the other methods.

(11) The thread of maximum velocity is at the surface for depths less that 2 feet and unobstructed flow at the lower end of the canal. For depths of 5 feet or more and discharge checked at the lower end of the canal this thread is from two-tenths to four-tenths depth below the surface, the mean for thirty-one experiments being thirty-one-hundredths depth. (See table on page 77.)

(12) The position of the thread of mean velocity varies from five-tenths depth for small depths to seventy-three-hundredths depth for the larger depths. For the thirty-one experiments by the ordinary method of series C and D it is sixty-four-hundredths depth below the surface. (See table on page 77.)

(13) The surface velocity is always greater than the bottom velocity with center of meter 0.25 foot above bottom. (See figs. 23 to 28.)

(14) The ratio of bottom velocity to mean velocity varies from 0.6 to 0.9, being 0.8 for the experiments of series A, 0.75 for series C, and 0.85 for series D. (See table on page 79.)

(15) The ratio of mean velocity to mid-depth velocity varies from 0.90 to 0.99, the mean of forty experiments being 0.95. (See table on page 79.)

(16) The average of the velocities 0.5 foot above the bottom and 0.5 foot below the surface is from −2.2 per cent to +30 per cent less than the mean velocity shown by the weir. (See table on page 83.)

(17) A small Price meter will revolve faster in moving water of a given velocity when held with a rigid rod than when held with a cable. (See table on page 89.) Hence the same rating table will not answer for both.

(18) The bottom velocity varies between so wide limits that it is not a desirable quantity to use in computing discharge; the mid-depth or the six-tenths-depth is better.

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